CEN WORKSHOP AGREEMENT

CWA 18409

July 2026

ICS 25.040.30

English version

Grasp-free, surface-based robotic manipulation - Vocabulary, characteristics, performance criteria and related test methods

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CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

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Foreword

This CEN Workshop Agreement (CWA 18409:2026) has been developed in accordance with the CEN-CENELEC Guide 29 "CEN/CENELEC Workshop Agreements – A rapid way to standardization" and with the relevant provisions of CEN/CENELEC Internal Regulations - Part 2. It was approved by the Workshop CEN "Grasp-free, surface-based robotic manipulation - Vocabulary, characteristics, performance criteria and related test methods", the secretariat of which is held by UNI consisting of representatives of interested parties on 2026-02-23, the constitution of which was supported by CEN following the public call for participation made on 2026-01-21. However, this CEN Workshop Agreement does not necessarily include all relevant stakeholders.

The final text of this CEN Workshop Agreement was provided to CEN and/or for publication on 2026-07-07.

Results incorporated in this CWA received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101069536.

The following organizations and individuals developed and approved this CEN Workshop Agreement:

a) IT University of Copenhagen – Kasper Stoy

b) ICONS – Chiara Bartolacci

c) Diana Cafiso (IIT – Istituto Italiano di tecnologia)

d) AVEC – Maria Nikolaidi

e) AVEC – Federica Chiarella

f) Trinity College Dublin – Ginevra Sanvitale

g) Cabinplant – Hansen Henning Ingemann

h) Brno University of Rechnology – Zdenek Materna

i) Reconfigurable Robotics Lab, EPFL – Serhat Demirtas

j) Reconfigurable Robotics Lab, EPFL – Ziqiao Wang

k) Reconfigurable Robotics Lab, EPFL –Yuhao Jiang

l) Reconfigurable Robotics Lab, EPFL – Jamie Paik

m) PhD student (IIT – Istituto Italiano di tecnologia) - Gayatri Indukumar

n) PhD student (IIT – Istituto Italiano di tecnologia) – Muhammad Awais

o) CEN/TC 310 – Steven Carter

p) UNI – Giovanni Miccichè

q) UNI – Federica Fugaroli

r) UNI – Emanuela Pisani

s) UNI – Cristina Dimaria

t) UNI – Elena Mocchio

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Introduction

This CEN/CENELEC Workshop Agreement is based on the results of the MOZART European project (Morphing Computerized mats with Embodied Sensing and Artificial Intelligence), grant agreement No 101069536.

The food processing industry is a sector of strategic importance for the European economy, providing essential employment and securing access to affordable, healthy and nutritious food. The sector remains highly dependent on manual handling, and demand is rising for food products with a low CO_2 footprint, such as vegetables, fish and chicken. These consumption trends are expected to grow as people and governments increasingly strive towards more environmentally conscious behaviour, placing the green transition of food production at the centre of the sector's development.

Automation has been successfully introduced for the growing, harvesting and packaging of fruit and vegetables, where the complete process from raw produce to a sales-ready package is now fully automated. The processing of fish and chicken, however, is still carried out largely by hand. This dependence on manual labour is increasingly difficult to sustain, given the shortage of factory workers and the recurring risk of supply disruption. Increasing the level of robotic automation in these industries is therefore both timely and necessary, and it offers a route to reduce production costs, support the shift towards more sustainable foods, and transform unskilled jobs into knowledge-based ones.

Fish and chicken processing is a typical example in which automation has not yet reached the final, most demanding stage of production. Even in highly mechanised plants, workers are still employed for the final presentation and packaging of the product, because current automation technology does not provide the manipulation capabilities required to handle soft, heterogenous objects beyond simple pick-and-place operations. The quality of the final product therefore continues to depend heavily on the manual skills of the operators:

- a reliable grip remains a challenge for chicken parts with potentially loose skin, independent of the gripping strategy used;
- packing requires the object to be oriented in three dimensions and squeezed into shape for the best possible presentation, which is difficult to achieve with current technology even when regrasp stations and similar solutions are used;
- the variability between individual products — in size, weight, shape and surface properties — makes conventional, rigid manipulators unsuitable for the task.

These manual tasks are often laborious, repetitive and low-paying, and are frequently carried out under demanding working conditions. Improving the working conditions of employees, and understanding the wider impact of new technology on society, are therefore as important as the technical innovation itself. For this reason, the technological development is complemented by social sciences and humanities research, so that the resulting automation is sustainable and inclusive in terms of gender, ability and background, and so that the effect of technological change on society is taken into account.

MOZART aims to deliver a step change in the robotic handling and manipulation of soft and heterogenous objects. Rather than refining existing gripper-based manipulators, the project develops a radically new approach based on deformable manipulation surfaces, referred to as Autonomous Manipulation using Morphing Modular Mats (AUTOMATs), coupled with an AI-powered control and learning framework. The manipulation surface changes its curvature locally and, through this, manipulates the objects resting on it, working side by side with human operators to complement the workforce.

This CEN/CENELEC Workshop Agreement is backed by the relevant existing standards in each specific domain, which are the main references for the development of these applications. The CWA is aimed at providing a description of the AUTOMAT technology, a soft, modular manipulation system built from a layered structure that can be configured into large manipulation surfaces, consisting of:

— a bottom electronics layer, built from standard components, that provides routing of communication and power and limited onboard computational power for local control and communication;

— a middle actuation layer, driven by a recently invented origami mechanism generalised to three degrees of freedom, which allows local control of the slope of the top layer;

— a top layer consisting of a highly compliant soft sensing skin that provides distributed tactile information and an appropriate stiffness distribution at the interface between the actuation layer and the food.

The hardware is complemented by an AI-powered framework for control and learning in distributed, modular systems, and by an integrative social sciences and humanities study that anticipates the challenges of deploying the technology in real production environments.

Depending on the application context, grasp-free surface-based manipulation systems may be deployed either as autonomous manipulation platforms or as assistive technologies supporting human operators in handling, positioning, orientation or preparation tasks.

1 Scope

This document applies to grasp-free, surface-based robotic manipulators.

It defines the relevant terminology (clause 3) and describes:

— the characteristics (clause 4),

— test conditions (clause 5),

— performance criteria, and methodologies for specifying and evaluating the manipulation performance (clause 6),

— uses cases (clause 7).

The informative annex A provides templates for presenting grasp-free, surface-based robotic manipulators characteristics, which can assist manufacturers in describing product features.

The informative annex B provides the results of studies on the psychosocial impacts of the application of robotic technologies in the process industry.

However, the document is not intended for verification or validation of safety requirements.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp/

— IEC Electropedia: available at http://www.electropedia.org/

3.1 Structures and elements

3.1.1
grasp-free surface-based manipulation system
system which, by means of a continuous surface, allows objects resting on it and held in place by gravity to be manipulated

3.1.2
grasp-free surface-based robotic manipulation system
grasp-free surface-based manipulation system (3.1.1), in which the topology of the surface is changed through actuation and, optionally, open-loop control or, with the addition of sensors, closed-loop control

3.1.3
mechanical sensor
sensor which detects mechanical stimuli such as pressure, shear, strain, translating it in a readable signal (e.g., change of electrical response, change of inductance)

3.1.4
Soft Inductive Sensor
mechanical sensor that can measure proximity, distance and pressure from a target object by measuring the change in coil inductance due to the interaction between a ferromagnetic or conductive target and the electromagnetic field produced by the coil usually facilitated with a deformable middle layer

3.1.5
Embedded sensor
sensor integrated in or beneath the surface, that allows to detect objects resting on the grasp-free surface-based robotic manipulation system (3.1.2)

3.1.6
Tactile sensor
embedded sensor that detects the presence or properties of an object through direct physical interaction with the surface

EXAMPLE Pressure sensor arrays, force/torque sensors, and capacitive touch sensors

3.1.7
External sensor
sensor positioned above or at the periphery of the grasp-free surface-based robotic manipulation system (3.1.2), that allows to detect objects resting on it

3.1.8
Optical sensor
external sensor (3.1.5) that detects objects by measuring reflected, transmitted, or emitted light

EXAMPLE Cameras (RGB, greyscale), structured light systems, laser triangulation sensors, and time-of-flight sensors

3.1.9
Thermal sensor
external sensor (3.1.5) that detects infrared radiation emitted or reflected by objects, enabling detection based on thermal contrast between the object and the manipulation surface

Note 1 to entry: Useful where optical contrast is insufficient or where object temperature is a relevant parameter.

3.1.10
Actuator
component that generates mechanical motion or force to modify the position and orientation of the surface of the grasp-free surface-based robotic manipulation system (3.1.2) and enables manipulation of objects on it

3.1.11
Rigid Actuator
actuator (3.1.6) composed of discrete, substantially non-deformable structural elements, in which motion arises from the relative displacement of such elements about defined kinematic joints

3.1.12
Electromagnetic Actuator
rigid actuator (3.1.6.1) in which mechanical motion is produced through the interaction of electric currents with magnetic fields, producing either rotational motion about a defined axis or translational motion along a defined axis

EXAMPLE Rotary variants include brushed and brushless direct current (DC) motors, stepper motors, and servomotors, optionally coupled with gear reducers or transmission mechanisms. Linear variants include solenoids, voice-coil actuators, and linear motors.

3.1.13
Rigid Pneumatic Actuator
rigid actuator (3.1.6.1) in which mechanical motion is produced through the controlled flow and pressurization of a compressible gas, typically air, acting upon rigid structural elements

EXAMPLE Single-acting and double-acting pneumatic cylinders, and rotary pneumatic vane motors.

3.1.14
Hydraulic Actuator
rigid actuator (3.1.6.1) in which mechanical motion is produced through the controlled flow and pressurization of an incompressible liquid, typically capable of delivering high force densities

EXAMPLE Hydraulic cylinders and rotary hydraulic motors.

3.1.15
Compliant Actuator
actuator (3.1.6) in which mechanical motion is produced through the continuous deformation of compliant materials, typically exhibiting distributed actuation, multiple degrees of freedom, and inherent mechanical compliance

Note 1 to entry: The inherent compliance of such actuators may be exploited for the safe handling of fragile or deformable objects.

3.1.16
Soft Pneumatic Actuator
compliant actuator (3.1.6.2) composed of elastomeric or otherwise deformable materials, in which motion is produced through pressurization by a compressible gas

EXAMPLE Fibre-reinforced elastomeric actuators, pneumatic artificial muscles, and pneu-net bending actuators.

3.1.17
Electroactive Polymer Actuator
compliant actuator (3.1.6.2) composed of polymeric materials that produce mechanical deformation in response to an applied electric field or current

EXAMPLE Dielectric elastomer actuators (DEAs), hydraulically amplified self-healing electrostatic (HASEL) actuators, and ionic polymer-metal composites (IPMCs).

3.1.18
Shape-Memory Actuator
compliant actuator (3.1.6.2) composed of materials that produce mechanical deformation through a thermally or otherwise induced phase transformation, returning to a previously programmed configuration

EXAMPLE Shape-memory alloy (SMA) actuators and shape-memory polymer (SMP) actuators.

3.2 Sensing in object handling

3.2.1
Sensor input
input that determines the response of the sensor

EXAMPLE Pressure, shear, temperature.

3.2.2
Sensor response
measurable output quantity generated by the sensor in response to the sensor input

Note 1 to entry: Sensor response depends on the transduction mechanism of the sensor.

EXAMPLE Variation of electrical resistance, inductance, transmitted light.

3.2.3
Sensitivity
minimum input of physical parameter that will create a detectable output change

Note 1 to entry: In some sensors, the sensitivity is defined as the input parameter change required to produce a standardized output change.

3.2.4
Linearity
deviation of the measured sensor response from a linear fitting

3.2.5
Tactile sensing
ability to detect when an external object comes into physical contact with the sensor

3.2.6
Proprioception
sensing of the system's own mechanical state and configuration

3.2.7
Proximity sensing
capability of a sensor to detect the presence, position, or distance of a nearby object without direct physical contact

3.2.8
Slip detection
detection of relative sliding motion between a contacted object and the sensor surface

3.2.9
Deformation sensing
capability to measure the change of shape and/or geometry caused by mechanical loading

3.3 Type of handling

3.3.1
Translation
handling that allows to move horizontally or vertically objects resting on the grasp-free surface-based robotic manipulation system (3.1.2)

3.3.2
Rotation
handling that allows to rotate in place or in combination with translation objects resting on the grasp-free surface-based robotic manipulation system (3.1.2)

3.3.3
Flipping
handling that allows objects to make a transition from one stable resting position to another

EXAMPLE An object is flipped from one side to the other side.

3.4 Functions

3.4.1
Object detection
function by which a system determines whether one or more objects of a specified class are present on the surface, without necessarily providing information about their spatial position or orientation

Note 1 to entry: The output of object detection is typically a binary or categorical classification indicating the presence or absence of each object class

3.4.2
Object localization
function by which a system determines the spatial position of one or more detected objects within a scene or coordinate frame

Note 1 to entry: Object localization extends object detection (3.4.1) by producing a spatial descriptor — such as a bounding region, centroid coordinate, or reference point — that characterizes where within the field of view each detected object is situated.

3.4.3
Pose estimation
function by which a system determines the position and orientation of one or more objects relative to a defined reference frame

Note 1 to entry: Pose estimation extends object localization (3.4.2) by additionally providing rotational parameters — expressed, for example, as Euler angles, a rotation matrix, or a quaternion — such that the full six-degrees-of-freedom configuration of each object is characterized.

3.4.4
Center of mass estimation
function by which a system determines the location of the centre of mass of one or more objects, based on geometric, photometric, or model-derived information

Note 1 to entry: Center of mass estimation extends pose estimation (3.4.3) by providing a physically meaningful reference point that accounts for the mass distribution of the object, which may differ from its geometric centroid, and which is of particular relevance to manipulation, grasping, and load-bearing applications.

4 Characteristics

4.1 Overview of grasp-free, surface-based robotic manipulation: description, purposes and limits

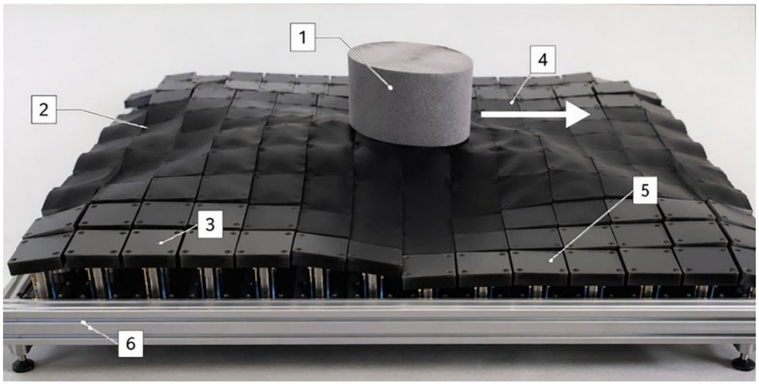
Grasp-free, surface-based robotic manipulation systems are essentially extensions of conventional one degree of freedom conveyor belts into surfaces with many degrees of freedom with local manipulation capabilities in both two and three dimensions. These systems may be implemented using modular rigid mechanisms, compliant origami-inspired mechanisms, or continuous soft surfaces actuated at discrete points (see Figure 1).

Actuators placed throughout the system allow actuation and thereby manipulation of objects independent of each other. The added actuation level also means that objects can be translated freely in the two-dimensional plane and in some implementations also vertically. However, the last dimension often to a limited degree. The actuation may also allow for rotation and flipping.

Sensors can either be placed overhead or embedded in the surface. This allows for closed-loop control of the manipulation of the objects.

The purpose of these manipulation systems is to fill a gap between conveyor belt and conventional grasp-based robotic manipulators. In contrast to graph-based robotic manipulators, surface-based manipulation lends itself better to parallel manipulation of multiple objects and the large contact-surface area allows for safely handling of soft or fragile objects.

While surface-based manipulation excels at manipulation over a large area they are limited when it comes to workspace and reach.



a) example of a complete system

b) example of modular rigid surface

c) example of continuous soft surface

d) example of object transportation

Key

1	object
2	manipulation surface
3	actuation unit (continuous or modular)
4	direction of object motion
5	embedded sensors
6	supporting structure

Figure 1 — Example of layered architecture of a grasp-free surface-based manipulation system with tactile sensing skin

Modularity and reconfigurability are important characteristics of grasp-free surface-based manipulation systems. Modular architectures may allow the adaptation of surface size, actuation density and manipulation capabilities to different object types, process requirements and production layouts. Such flexibility can facilitate system scalability and support deployment across multiple application domains. While specific implementations may be developed for particular use cases, the underlying manipulation principles may be transferable to a broad range of sectors involving delicate, deformable or irregular objects.

4.2 Actuation technology

A system can be characterized through the per-module degrees of freedom of actuation. A continuous surface covering modules can reduce the density of modules and actuators. Actuators are controlled through a range of approaches such as centralized and distributed control and open-looped and closed-looped control.

4.3 Interoperability and system integration

Interoperability refers to the ability of a grasp-free surface-based manipulation system to exchange information and operate in conjunction with external automation and control systems.

Relevant interfaces may include communication with programmable logic controllers (PLCs), machine vision systems, supervisory control systems, human-machine interfaces (HMIs) and manufacturing execution systems (MES).

Where applicable, manufacturers should specify the available communication and integration interfaces supported by the system.

4.4 Dimensions

Geometric properties of the manipulation surface and its constituent components, including but not limited to active surface area, working envelope, surface flatness, and dimensional tolerances, determine the spatial constraints within which object manipulation can be performed and govern compatibility with objects and the installation environment. Dimensional characteristics shall be specified with respect to their impact on object manipulability, including minimum object size relative to actuator spacing.

4.5 Materials

Material specification determines the mechanical, chemical, and tribological properties of the system that governs its interaction with objects resting upon it under operational conditions. They can be divided into structural none-contact materials (modules, actuators) and functional contact materials (soft layer, coatings). The last is related to object integrity in clause 6.

4.6 Strength

The manipulation surface and its supporting structure shall withstand mechanical loads imposed by objects resting upon it, including static loads, dynamic loads arising during manipulation, and any concentrated loads, without failure or permanent deformation beyond specified limits.

4.7 Deformability

The deformability of grasp-free, surface-based robotic manipulation systems shall be characterized with respect to its effect on manipulation accuracy and repeatability.

4.8 Characteristics of surface finishes

Surface finish directly governs the tribological interaction between the manipulation surface and resting objects and shall be specified with respect to its influence on friction, wear, and object motion behaviour.

4.9 Hygiene and release of substances

Requirements relating to cleanliness, microbial resistance, and the absence of harmful substance migration are of particular relevance where the system is intended to manipulate objects in food contact, medical, pharmaceutical, or other regulated environments.

For food-processing applications, hygiene considerations may also include cleanability, resistance to repeated wash-down procedures, compatibility with cleaning and sanitising agents, minimisation of contamination traps and verification of cleaning effectiveness.

5 Test conditions

5.1 Operational mode

The declared operational mode shall specify the conditions under which manipulation is performed.

This shall include, where applicable:

— whether manipulation is achieved using static deformation or time-varying actuation patterns;

— whether control is implemented in open-loop or closed-loop configuration;

— whether control is centralized or distributed.

Where relevant, the declared operational mode shall also specify whether manipulation is achieved through coordinated or periodic motion patterns (e.g. oscillatory or wave-based actuation).

5.2 Test configuration and trial

5.2.1 General

Performance requirements defined in Clause 6 shall be independent of the specified operational mode and test configuration, which shall be considered as boundary conditions for testing.

The test configuration and test conditions shall be defined in a manner that ensures reproducibility and traceability of the results.

The information required to define the test configuration and conditions may be declared using the formats provided in Annex A.

5.2.2 System configuration

The test configuration shall include a description of the system under test, including, where applicable:

— the spatial arrangement and number of actuators or modules;

— the distance between actuation points or modules;

— whether the manipulation surface is discrete or continuous;

— the degrees of freedom available per module or actuation unit;

— the presence and configuration of sensing systems.

Different deployment scenarios may impose different requirements on system configuration, integration and operational flexibility. These considerations may influence the suitability of a given system architecture for a particular application environment.

5.2.3 Operating conditions

The test conditions shall specify the operating parameters applied during testing, including, where applicable:

— the actuation pattern (e.g. static, periodic, or time-varying);

— relevant actuation parameters, such as amplitude, frequency, phase, or equivalent control variables;

— any environmental conditions that may influence system behaviour.

5.2.4 Reference objects

The reference objects used in the tests shall be declared with respect to their relevant properties, including, where applicable:

— mass;

— geometry and dimensions;

— surface characteristics (e.g. friction, roughness);

— material properties where relevant to manipulation performance.

5.2.5 Object–surface interaction

Where relevant, the interaction mechanisms between the object and the manipulation surface (e.g. rolling, sliding, sticking, or deformation-based interaction) shall be described.

5.2.6 Initial conditions and repeatability

The initial conditions of the test, including object placement and system state, shall be defined or documented in a reproducible manner.

Where variability cannot be eliminated, it shall be controlled or statistically characterized.

5.2.7 Relation to performance evaluation

The configuration and conditions defined in this clause may influence the measured performance but shall not constitute performance criteria.

Performance shall be evaluated exclusively according to Clause 6.

6 Performance

6.1 General

This clause defines performance criteria for grasp-free, surface-based robotic manipulation systems, together with the associated test methods. Performance criteria are grouped into two categories:

— basic performance (6.2), addressing the intrinsic capabilities of the manipulation surface itself;

— manipulation performance (6.3 to 6.6), addressing the system's ability to translate, rotate, flip, and preserve the integrity of objects.

Unless otherwise specified, each test procedure defined in this clause shall be repeated for a minimum of 10 trials, and results shall be reported as the mean value together with the standard deviation across trials.

Unless otherwise specified in an individual subclause, the tests defined in this clause require:

— the system under test, configured according to clause 5;

— one or more reference objects of declared mass, geometry, and, where applicable, moment of inertia, stable resting configurations, or pre-test condition;

— measurement equipment appropriate to the quantity being evaluated, with accuracy sufficient to resolve the declared performance level.

Characteristics of the system declared under clause 4 may be referenced as preconditions for the tests defined below, but shall not themselves constitute performance criteria.

6.2 Basic performance

6.2.1 Maximum no-load actuation velocity

Purpose: To quantify the maximum velocity achievable by the manipulation surface under no-load conditions as a measure of the system's intrinsic actuation capability.

Test procedure: The system shall be commanded to actuate at maximum demand along each declared actuation direction. The velocity of the actuated surface shall be recorded throughout the motion, and the peak value is identified.

Result: The maximum no-load velocity, expressed in metres per second or angles per second, shall be reported in all actuation directions.

6.2.2 Maximum surface actuation force

Purpose: To quantify the maximum horizontal force that the manipulation surface can exert on a resting object.

Test procedure: The object shall be placed on the surface and mechanically constrained via a calibrated load cell. The system shall be commanded to apply actuation in the direction under test, with actuation demand increased incrementally until either the declared actuation limit is reached or slip occurs between the object and the surface. The force at which slip occurs, or the maximum sustained force, shall be recorded.

Result: The maximum actuation force, expressed in Newtons, shall be reported per actuation direction.

6.2.3 Maximum surface actuation torque

Purpose: To quantify the maximum torque that the manipulation surface can exert on a resting object about a vertical axis.

Test procedure: Analogous to 6.2.2, with actuation commanded to rotate the object about a vertical axis rather than translate it, using a torque measurement system and a reference object of declared moment of inertia. The torque at which slip occurs, or the maximum sustained torque, shall be recorded.

Result: The maximum actuation torque, expressed in newton-metres, shall be reported.

6.3 Object translation performance

6.3.1 Translation speed

Purpose: To quantify the speed at which a resting object can be translated between two defined positions on the manipulation surface.

Test procedure: The object shall be placed at a defined starting position. The system shall be commanded to translate the object to a defined target position separated by a declared distance. The elapsed time between commanded motion onset and the object entering a defined tolerance region around the target shall be recorded.

Result: The mean translation speed, expressed in metres per second, shall be reported.

6.3.2 Translation accuracy

Purpose: To quantify the positional error between the final resting position of a translated object and its commanded target position.

Test procedure: The object shall be translated to a commanded target position as in 6.3.1. Once the object has come to rest, its final position shall be measured relative to the commanded target. Target positions shall be distributed across the declared working envelope.

Result: The translation accuracy shall be reported as the mean Euclidean distance between final and commanded positions, expressed in millimetres. The standard deviation across trials shall be additionally reported as the translation repeatability.

6.4 Object rotation performance

6.4.1 Rotation angular speed

Purpose: To quantify the angular speed at which a resting object can be rotated in place about a vertical axis.

Test procedure: The object shall be placed at a defined starting position and orientation. The system shall be commanded to rotate the object by a declared angle. The elapsed time between commanded motion onset and the object entering a defined angular tolerance region around the target orientation shall be recorded.

Result: The mean angular speed, expressed in radians per second, shall be reported.

6.4.2 Rotation accuracy

Purpose: To quantify the angular error between the final orientation of a rotated object and its commanded target orientation.

Test procedure: The object shall be rotated to a commanded target orientation as in 6.4.1. Once the object has come to rest, its final orientation shall be measured relative to the commanded target. Target orientations shall be distributed over the full rotational range.

Result: The rotation accuracy shall be reported as the mean absolute angular error, expressed in degrees. The standard deviation across trials shall be additionally reported as the rotation repeatability.

6.5 Object flipping performance

6.5.1 Flipping speed

Purpose: To quantify the time required to transition an object from one stable resting position to another (see 3.3.2).

Test procedure: The object shall be placed on the surface in a declared initial stable configuration. The system shall be commanded to flip the object to a declared target stable configuration. The elapsed time between commanded motion onset and the object reaching stable rest in the target configuration shall be recorded.

Result: The mean flipping time, expressed in seconds, shall be reported.

6.5.2 Flipping success rate

Purpose: To quantify the proportion of flipping attempts that result in the object reaching the commanded target stable configuration.

Test procedure: The flipping procedure defined in 6.5.1 shall be executed. Each trial shall be classified as successful if, within a declared settling time, the object is at rest in the commanded target configuration, and as unsuccessful otherwise. Failure modes (e.g. object returning to initial configuration, reaching an unintended stable configuration, leaving the surface) shall be recorded.

Result: The flipping success rate shall be reported as the ratio of successful trials to total trials, expressed as a percentage, together with a breakdown of observed failure modes.

6.6 Payload and object integrity

6.6.1 General

For many applications involving delicate, deformable or heterogeneous objects, system performance may depend not only on manipulation efficiency but also on the ability to preserve object quality and integrity throughout the manipulation process.

Relevant considerations may include minimising product damage, maintaining visual quality, reducing material loss and ensuring repeatable handling outcomes.

Depending on the application domain, object integrity may be evaluated through indicators such as deformation, breakage, tearing, bruising, surface damage, drip loss, loss of visual quality or yield reduction.

6.6.2 Maximum payload

Purpose: To quantify the maximum mass of an object that can be manipulated by the system while preserving declared manipulation performance.

Test procedure: A set of reference objects of varying declared mass but geometrically consistent contact footprints shall be used. The translation tests (6.3.1, 6.3.2) and rotation tests (6.4.1, 6.4.2) shall be repeated with reference objects of progressively increasing mass. For each mass, translation speed, translation accuracy, rotation angular speed, and rotation accuracy shall be recorded. The maximum payload shall be the greatest declared mass for which all applicable performance thresholds declared by the manufacturer for translation and rotation are met under the specified test conditions.

Result: The maximum payload, expressed in kilograms, shall be reported together with the performance criteria used as the qualifying threshold.

6.6.3 Object integrity preservation

Purpose: To quantify the extent to which the manipulation process induces damage or unintended modification to manipulated objects.

Test procedure: A population of reference objects with declared pre-test condition, and an inspection procedure capable of detecting relevant damage modes (e.g. visual inspection, dimensional measurement, functional testing), shall be used. Each reference object shall be inspected according to the declared procedure and its pre-test condition recorded. The object shall then be subjected to a declared manipulation sequence representative of the intended application. Upon completion, the object shall be re-inspected using the same procedure, and any changes relative to the pre-test condition shall be recorded.

Result: The object integrity preservation shall be reported as the proportion of objects exhibiting no detectable damage after manipulation, together with a description of the damage modes observed and the inspection procedure used.

7 Use cases

7.1 General

The following descriptions illustrate how the requirements of this document are intended to be understood and applied across different organizational and production settings, without prescribing specific technical solutions, equipment, designs or implementation approaches.

Such use cases are representative of application domains where surface-based manipulation offers advantages over grasp-based approaches.

7.2 Size grading system

This description outlines a representative application of a grading system for chicken fillets within food processing and distribution operations. It applies to industrial environments where chicken fillets are assessed as part of routine processing, quality control, and product release activities. The involved parties include production operators handling the fillets, quality assurance personnel responsible for ensuring compliance with defined quality criteria, and auditors or inspectors verifying conformity with applicable regulations. Additional stakeholders may include system maintainers and downstream customers who depend on consistent and reliable grading outcomes.

The purpose of this application scenario is to support uniform and dependable grading of chicken fillets to enable appropriate sorting, handling, and commercial decisions. The interactions include presenting fillets for grading, receiving grading results, and using those results to guide subsequent operational steps such as acceptance, rejection, or categorization. The scenario reflects both normal and peak production conditions, as well as expected variability in raw material characteristics.

Quality considerations highlighted include the accuracy and repeatability of grading results, robustness under typical food processing conditions, traceability of grading decisions, and timely availability of results so as not to disrupt production flow. Hygiene, food safety, and regulatory compliance are inherent aspects of the operational context.

7.3 Automatic packing system

This description outlines a representative application related to the packing and styling of chicken parts in trays within food production operations. It applies to industrial processing environments where chicken parts are arranged, portioned, and packaged to meet defined product, quality, and presentation requirements prior to distribution. (See Figure 2)

The involved parties include production operators responsible for tray loading and alignment, quality assurance personnel ensuring conformity with product specifications, and auditors or inspectors verifying compliance with food safety and labelling regulations. Additional stakeholders may include system maintainers and downstream customers, such as retailers, who rely on consistent product appearance and pack integrity.

The purpose of this application scenario is to support consistent packing and visual presentation of chicken parts to enable efficient downstream handling, consumer acceptance, and commercial differentiation. The interactions involve placing chicken parts into trays, confirming correct arrangement and portion composition, and preparing packs for subsequent sealing, labelling, or inspection steps. The scenario considers variations in production speed, product sizes, and operational conditions typical of food manufacturing environments.

Quality considerations highlighted include repeatability of packing outcomes, robustness of operations under normal and peak production loads, hygienic handling of food products, and traceability of packing decisions. Product presentation consistency, minimization of product damage, and timeliness to maintain production flow are also emphasized.

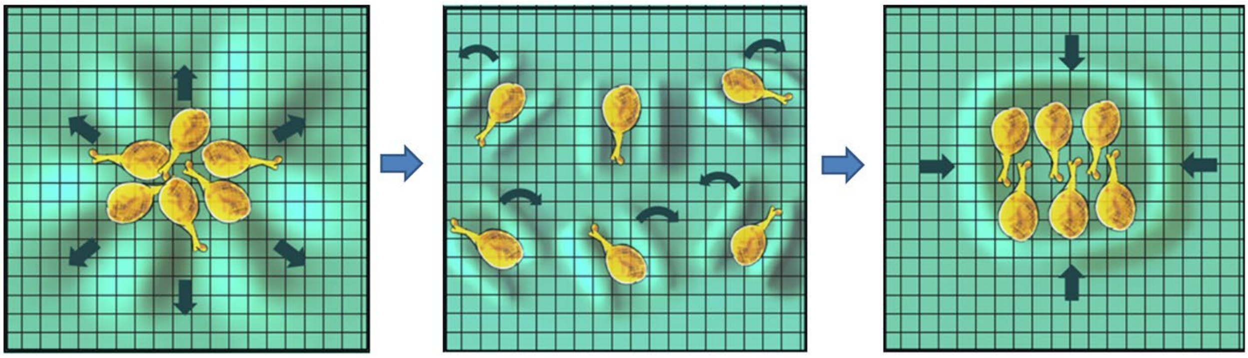


Figure 2 — Examples of automatic arrangement and packing of chicken parts on a surface-based manipulation system

7.4 Assisted handling and rotation of cooked skipjack tuna during skin removal

In this use case, the grasp-free manipulation surface supports the handling, stabilisation and controlled rotation of cooked skipjack tuna during skin-removal operations, while the removal process itself may still involve human intervention or complementary equipment. It applies to production environments where cooked tuna is prepared for further portioning, packing, or secondary processing steps. (See Figure 3.)

The parties involved include production operators overseeing processing lines, quality assurance personnel responsible for product quality and compliance, and auditors or inspectors verifying adherence to food safety and regulatory requirements. Additional stakeholders may include system maintainers and downstream processors relying on consistent product characteristics.

The purpose of this application scenario is to support reliable and efficient separation of skin from cooked Skipjack tuna while preserving the integrity and yield of the edible product. Interactions include presenting cooked tuna to the skin removal process, obtaining skin free tuna portions, and transferring the product to subsequent processing or packaging stages. The scenario reflects normal and peak production conditions, as well as expected variability in raw material size, shape, and cooking outcomes.

Quality considerations highlighted include consistency of skin removal results, minimization of product loss or damage, robustness under typical seafood processing conditions, and hygienic operation in compliance with food safety standards. Traceability of processing outcomes, ease of verification, and timely operation to maintain production flow are also emphasized.

Annex A
(informative)

Manufacturer's declaration of characteristics for deformable manipulation surfaces (DMS)

A.1 General

Format A1 is used to present the characteristics of an existing or planned grasp-free, surface-based (deformable) manipulation system.

Manufacturers describe the characteristics of their product by completing the “Declared value” column below. Where a row is not applicable to a given product, it should be marked “n/a”. The “Reference/notes” column indicates the clause of this document from which the characteristic is derived; performance values (Section 5) should be reported as the mean together with the standard deviation across a minimum of 10 trials (see 6.1).

Sections 1 to 4 identify and configure the system, Section 5 reports measurable performance (clause 6), Section 6 covers materials and durability (clause 4), Section 7 covers the operating environment and reference objects (clause 5), and Section 8 covers safety, ergonomics and human-factors characteristics derived from Annex B and the human-factors agreements it references (CWA 17835:2022 and CWA 17663:2021).

A.2 Format A1

Characteristic	Unit / format	Declared value	Reference/notes
1. Manufacturer and product identification			
DMS manufacturer (name)	*text*		
Manufacturer address	*text*		
DMS model	*text*		
DMS type	*modular-rigid / origami-compliant / continuous-soft*		4.1
Intended applications	*text*		
2. System configuration			
Surface type	*discrete / continuous*		4.1, 5.2
Active surface area	m^2		4.4
Dimensions per module	$m \times m$ / m^2		4.4
Distance between actuation points / modules	*m*		5.2

Characteristic	Unit / format	Declared value	Reference/notes
Degrees of freedom per module	*count*		4.2, 5.2
Number of modules	*count*		5.2
Control architecture	- *centralized / distributed;* - *open- / closed-loop*		4.2, 5.1
Actuation pattern	*static / periodic / time-varying*		5.3
3. Actuators			
Type of actuators	*text*		4.2
Number of actuators per module	*count*		
Rated actuator power per module	*W*		
4. Sensing			
Sensing functions	*tactile / pose est. / CoM est. / vision*		3.4, 4
Sensor placement	*embedded / overhead*		4
5. Performance characteristics (mean ± standard deviation, ≥ 10 trials)			
Maximum no-load actuation velocity	*m/s or °/s*		6.2.1
Maximum surface actuation force	*N*		6.2.2
Maximum surface actuation torque	*N·m*		6.2.3
Translation speed	*m/s*		6.3.1
Translation accuracy / repeatability	*mm*		6.3.2
Rotation angular speed	*rad/s*		6.4.1
Rotation accuracy / repeatability	*degrees*		6.4.2
Flipping speed	*s*		6.5.1

Characteristic	Unit / format	Declared value	Reference/notes
Flipping success rate	*%*		6.5.2
Maximum payload	*kg*		6.6.1
Maximum vertical manipulation force	*N*		
Object integrity preservation	*% undamaged*		6.6.2
6. Materials, structure and durability			
Structural (non-contact) materials	*text*		4.5
Functional (contact) materials — soft layer, coatings	*text*		4.5
Strength / load capacity (static, dynamic, concentrated)	*N or kg*		4.6
Deformability characterization	*text / value*		4.7
Surface finish / friction characteristics	*text*		4.8
Hygiene & release of substances (food-contact compliance)	*standard ref / text*		4.9
7. Operating environment and reference objects			
Operating environment	*text*		5.3
Operating temperature range	*°C*		
Reference object geometry (shape, dimensions)	*m*		5.4
Reference object mass range	*kg*		5.4
Object surface characteristics (friction, roughness)	*text*		5.4
8. Safety, ergonomics and human factors			

Characteristic	Unit / format	Declared value	Reference/notes
Designed for human-robot collaboration	*yes / no*		Annex B; CWA 17835:2022
Mechanical-hazard safety testing performed	- *yes / no;* - *protocol ref*		CWA 17835:2022
Safety functions (e-stop, force/speed limiting, collision detection)	*text*		Annex B
Noise emission level	*dB(A)*		ergonomic stressor
Suitability for cold processing environments	- *°C;* - *yes / no*		Annex B (cold = key WRMSD factor)
Repetitive / strenuous manual tasks displaced	*text*		Annex B (WRMSD mitigation)
Residual operator physical interaction (lifting, reach, posture)	*text*		Annex B (HFE)
Worker-satisfaction assessment supported	- *yes / no;* - *methodology*		CWA 17663:2021
Operator transparency / capability cues during operation	*text*		Annex B (SDU VR study)
Onboarding / training requirements	*text*		Annex B
Cleaning / maintenance accessibility	*text*		—

NOTE Section 8 supports the declaration of human-factors and ergonomic characteristics relevant to collaborative deployment. The literature reviewed in Annex B identifies cold environments and repetitive, machine-paced work as the dominant causes of work-related musculoskeletal disorders in food processing; the corresponding rows allow a manufacturer to declare how the system addresses these factors.

Annex B
(informative)

Psychosocial impacts of the application of robotic technologies in the process industry

B.1 General

This annex provides an overview of the psychosocial dimension associated with the application of robotic technologies, focusing on the poultry processing sector as a potential field of application.

The first part (clauses B.2 and B.3) describes health and safety hazards in the sector, which are often connected with psychosocial factors, offering insights on existing standards and best practices to address these factors at the organisational level.

The second part (clauses B.4 and B.5) focuses on the factors influencing trust and acceptance of new technology at the level of individual operators, providing guidelines based on interviews to industry professionals and a Virtual Reality experiment.

B.2 Health and safety hazards in the food industry

This section provides a review of the main findings emerging from Human Factors and Ergonomics (HFE) and Social Sciences and Humanities (SSH) research on labour in the industrial poultry processing sector. Psychosocial factors are closely related to the development of musculoskeletal disorders, as discussed in a review by Bezzina et al [1]. This underscores the importance of attending to the psychosocial dimension of labour in the food processing industry, as well as the necessity to adopt a multi-level approach in addressing this dimension.

MOZART Deliverable 5.2 [2], which analysed 21 HFE articles and 17 SSH articles, highlights how the implementation of machinery and production systems can both improve and exacerbate labour conditions in poultry processing environments.

Across the dataset, a limited number of positive attributes associated with industrial poultry processing work emerged. These include opportunities for human interaction, income generation, task variety, and forms of skilled manual work described as “building with hands.” Such aspects suggest that, despite the highly industrialized character of the sector, workers can still experience dimensions of sociality, craftsmanship, and occupational diversity.

However, the literature overwhelmingly emphasizes the negative dimensions of labour in industrial poultry processing. Recurrent issues include health and safety concerns, repetitive work, machine-paced production rhythms, heavy physical labour, low pay, labour shortages, and high turnover associated with subcontracted and temporary employment. Workers are also affected by scheduling instability, upper-management pressures, and deskilling processes linked to automation and standardization. In several studies, existing guidelines and regulations are portrayed as insufficient or poorly adapted to workers’ realities, while tools and machinery are often described as inefficient or contributing to workplace strain rather than alleviating it.

Health-related findings consistently identify musculoskeletal disorders affecting the lower limbs, fingers, wrists, elbows, shoulders, and different sections of the spine, with the dominant hand and forearm especially exposed to strain. Two central factors repeatedly emerge as causes of these disorders: cold temperatures and repetitive work. Cold conditions characterize the broader processing environment and are especially impactful in hand-intensive tasks, while repetitive and machine-paced labour intensifies physical stress on workers’ bodies. HFE studies further demonstrate how work pace, task design, and environmental conditions constitute core concerns of ergonomics research and intervention in poultry processing facilities.

Similar findings emerge from a review by Crandall et al. [3] that examines the effectiveness of workplace management strategies aimed at reducing work-related musculoskeletal disorders (WRMSDs) in the poultry processing industry. Drawing on a systematic review of 45 publications, the study evaluates a range of interventions including personal protective equipment, ergonomic training, job rotation, tool design, automation, and robotics.

The review confirms that poultry processing workers face particularly high risks of WRMSDs due to repetitive movements, intense physical strain, and prolonged exposure to cold environments. These factors are consistently identified as structural features of industrial poultry processing work and are associated with injuries affecting the hands, wrists, forearms, shoulders, spine, and lower limbs.

B.3 Guidelines for the mitigation of health and safety hazards

B.3.1 Literature findings

In the review in Deliverable 5.2 [2], task rotation appears throughout the literature as one of the primary mitigation strategies employed to reduce workplace-related injuries and musculoskeletal disorders.

Nevertheless, the effectiveness of such interventions is often constrained by the broader organization of industrial production, where repetitive manual tasks and machine-led pacing continue to shape workers' experiences. Overall, the findings suggest that technological implementation in poultry processing cannot be understood solely in terms of productivity gains, but must also be evaluated through its consequences for worker health, autonomy, job quality, and social relations within the workplace.

Crandall et al. [3] identify several effective interventions for reducing WRMSDs in poultry processing facilities. These include formal commitments from senior management to dedicate adequate financial and organizational resources to prevention efforts, comprehensive ergonomic assessments focused on high-risk tasks, and specialized evaluations of workers engaged in knife-related activities and exposed to cold working conditions. The review further highlights the importance of continuous training and educational programs, particularly for new employees, alongside the adoption of a hierarchy-of-controls framework applied systematically across different levels of workplace organization. Finally, the study highlights the importance of coordination and knowledge-sharing across the sector. Successful strategies involving automation and ergonomic innovation can be disseminated through professional associations, meetings, and other collaborative platforms, enabling facilities to adopt interventions that improve worker health and safety conditions.

These findings confirm that ergonomic processes implemented at the organizational level can significantly reduce WRMSD rates only insofar they combine institutional support, active worker involvement, early injury detection and reporting practices, and the tailoring interventions to diverse workforce needs. Facilities adopting systematic ergonomic changes report improved outcomes, particularly where prevention strategies are integrated into everyday workplace practices rather than treated as isolated interventions.

B.3.2 Existing CEN agreements

Additional insights on how to comply with health and safety regulations and best practices in the implementation of MOZART technologies can be derived by existing CEN agreements:

a) CWA 17663:2021, *Measurement of Worker Satisfaction in Automated Systems – Methodology*

   This agreement provides a standardized methodology for assessing the psychosocial impacts of automation and human-robot work-station design. Although separate from formal risk assessment, it can complement safety evaluations by enabling reliable, context-specific measurement of worker satisfaction. The methodology supports the development of psychometric tools through three main stages: exploratory study, questionnaire design, and experimental study. The exploratory stage involves collecting data from participants to develop an understanding of the relevant psychological dimensions and contextual factors to be analysed. The questionnaire design stage then translates these findings into an initial survey instrument, structured for clarity, accessibility, and ease of response, forming the basis of the psychometric tool. Finally, the experimental stage involves administering the questionnaire, followed by testing and analysing the results to validate and refine the instrument.

b) CWA 17835:2022, *Guidelines for the development and use of safety testing procedures in human-robot collaboration*

This agreement establishes a common framework for the development and application of safety testing procedures in collaborative human-robot systems across different robot categories and application scenarios, including industrial environments. It focuses specifically on mechanical hazards and defines key safety-relevant human-robot collaboration skills, system-level testing approaches, and a standardized validation protocol template that can be applied across multiple domains. The document also provides an overview of test methods for assessing mechanical hazards in robotic applications, offering a useful reference to support the implementation and harmonisation of safety testing procedures.

B.4 Trust and acceptance factors in industrial HRC

Whether a new system improves or worsens working conditions depends not only on its physical design and the organisational practices surrounding its implementation, but also on whether workers can understand it, rely on it appropriately, and accept it into their daily practice. This section focuses on this dimension. It draws on two sources of data: an experiment on how the framing of the robot shapes perceived trustworthiness, and a thematic analysis of interviews with food-industry stakeholders.

The rapid development of AI and robotics has made automation a reality across industry, including food processing. The benefits are real: automation can improve efficiency and accuracy. But the rapid deployment of these systems also introduces new risks that can hinder effective human-automation teaming, or even put operators in hazardous situations [6]. Mechanical safety is therefore not the only concern. Effective and safe interaction also requires operators to rely on the system adequately, neither too much nor too little [7].

This balance is critical to avoid miscalibration, which appears in two forms. Under reliance is not relying on a system that is actually correct. It arises from underestimating the system's capabilities and can lead operators to reject useful automation. Overreliance is relying on a system that is actually incorrect. It arises from overestimating the system's capabilities and, influenced by automation bias [8], increases the risk of overlooking the system's errors.

To mitigate both, the operator's expectations of the system must continually align with what the system can actually do. Operators need to assess the system correctly, and to do this they interpret the available information with respect to the system's trustworthiness. Any information element used to make such an assessment is a trustworthiness cue [9] [10]. Cues come from the system, from the environment, and from what operators are told before first use. This last source is easily overlooked: onboarding and training shape reliance across the whole interaction life-cycle, before use, during use, and after errors [11] [12].

B.5 Guidelines to improve calibrated trust in the system and acceptance factors

B.5.1 Framing as a trustworthiness cue: a VR experiment

A between-subjects VR experiment (N = 21) tested how framing affects operator perceived trustworthiness of the system. Participants supervised a simulated poultry packing line, utilizing the virtual simulation of the MOZART, and could stop it or speed it up. Everyone saw the same system, only the framing changed.

One group (C1) was told that the system was an early student prototype. The other interaction group (C2) was told it was an advanced, well-tested system. The group given the high-capability framing rated the system as more competent (d = 1,59) and acted on it sooner, despite identical system behaviour [13]. This confirms that what operators are told beforehand is itself a trustworthiness cue. Poor framing is a risk: oversold systems invite overreliance; undersold ones invite underuse.

B.5.2 Conditions for acceptance: stakeholder interviews

Empirical material was gathered at the 2026 International Production & Processing Expo (IPPE) in Atlanta, the largest annual trade fair for the poultry, meat, and animal-feed industries. The setting gave direct access to industry professionals — integrators, plant managers, engineers, and vendors — who work with automation in poultry processing day to day. Data came from roughly 29 informal conversations and open-ended questionnaire responses, in which participants reflected on what would make an automated system like MOZART acceptable in their plants. The interviews were analysed with thematic analysis [14].

Three patterns stood out:

— **Acceptance depends on partnership, not novelty.** Respondents care less about an impressive robot and more about whether a reliable partner stands behind it. They want service, fast repairs, spare parts, and a stable vendor;

— **Acceptance is shaped by the food-processing context.** The robot is judged by whether it survives water, chemicals, debris, and constant cleaning, and whether it passes hygiene audits. Respondents are sceptical of polished demo videos, because real plants are messy;

— **Acceptance requires bounded, transparent automation.** Respondents want predictable behaviour they can understand, supervise, and recover when it fails. "AI magic" gets rejected fast. They want clear status, an obvious stop and recovery option, and automation that supports human oversight rather than replacing it.

These findings line up with established design guidance for trustworthy automation [11]. They translate into concrete recommendations for the MOZART demonstrator:

1. **Set accurate expectations**. Onboarding and capability descriptions should match what the system can do, neither overstating nor understating it;

2. **Let operators verify operation**. The system should provide cues during use so operators can confirm, revise, or reject their initial expectations;

3. **Convey uncertainty and limits**. The system should signal when it is unsure and when intervention is needed;

4. **Support error recovery**. The system should provide clear, fail-safe behaviour and an obvious way to stop and recover;

5. **Meet the operating context**. Serviceability and washdown should suit a wet, regulated environment;

6. **Design a simple interface**. Clear status, a visible stop/recover function, and separate operator and maintenance views;

7. **Provide training**. Operators should be trained to oversee the system, including how and why it can fail, so they keep appropriate reliance.

B.6 Conclusion

Addressing psychosocial factors in the poultry processing industry requires a multi-level approach that considers the broader organisation of production within the sector, the expectations of managers and other stakeholders, and the specific needs and perceptions of day-to-day operators.

At a broader organisational level, several psychosocial factors can negatively affect labour, including scheduling instability, pressure from upper management, deskilling processes, and high employee turnover. Combined with the structural characteristics of poultry processing work, such as cold working environments and repetitive tasks, these factors can also have adverse effects on workers' physical well-being. Prevention strategies need to be integrated into everyday workplace practices and developed with the active involvement of workers.

Trust and acceptance have to be addressed before implementation, not after. How the system is framed, explained, and supported shapes reliance before and during use, and poor framing carries its own risk of miscalibration.

On the managerial level, acceptance relies on multiple factors: service, vendor stability, hygiene standards, but also transparency on the system's capabilities. The system is not judged and evaluated as a stand-alone product, but rather as a part of a longer relationship, including support and accountability.

On the operator's level, acceptance depends on whether the system is predictable, understandable, and can recover from potential errors in daily use. Operators need to know how the system behaves, how it fails and when its capabilities are conveyed honestly so that they can rely on it appropriately.

Finally, from the evidence gathered, which was specific to poultry processing, it can be assumed principles involving calibrated trust, transparency, or vendor-client relationships are not limited to the poultry industry. It can be reasonably assumed the same applies to the other sectors in the food processing industry, including fish production.

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