Handling with AI-enhanced Robotic Technologies for flexible ManUfacturing

D1.4

HUMAN CENTRIC DESIGN GUIDANCE AND SKILLS TRANSFORMATION MAP

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HARTU Consortium

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Executive Summary

This document presents the work carried out to define the new skills required of operators in the TO-BE scenarios envisioned within the Industry 5.0 context, such as the use cases addressed in the HARTU project.

The first part introduces the *Skill–Task Mapping* tool developed to support data collection and subsequent analysis. Based on a literature review and insights gathered during workshops with project partners, a structured *list of skills*—organised into eight categories—has been defined.

The second part presents the *Skills Transformation Map*, which describes the three new human profiles (i.e. *Smart Line Operator, Plant Flow Keeper, Tech Solver*) expected to operate in future Industry 5.0 scenarios, together with their associated tasks and skills. The *Skills Transformation Map* has been implemented as an interactive tool equipped with section-specific charts, enabling users to navigate and explore the data according to their interests (e.g., identifying the most relevant skills across operator profiles or analysing the tasks carried out by a specific human role).

Finally, the document introduces the *Human-Centric Design and Training Guidance*. This set of guidelines and sub-guidelines, organised into five sections (i.e. *Procedures, workspace and working practices, Human Performance Transition Factors, Teams & Communication, Skills, roles and responsibilities, Ethics and Liability*) and divided into design and training guidelines, is intended to support design teams in the transition toward and development of smart manufacturing work environments. The *Guidance* ensures that human factors and user experience considerations are integrated throughout the design process and that appropriate training programmes can be planned to prepare operators whose roles will evolve and require new competencies.

Together, the *Skills Transformation Map* and the *Human-Centric Design and Training Guidance* provide direction on how to develop acceptable and trustworthy solutions for smart manufacturing, as well as how to customise training programmes to ensure proper operator preparation.

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Acronyms

List of the acronyms	
AGV	Automated Guided Vehicle
AR	Augmented Reality
HARTU	Handling with AI-enhanced Robotic Technologies for flexible manufactUring
HCD	Human-Centric Design
KPI	Key Performance Indicator
MES	Manufacturing Execution System
SSH	Social Sciences and Humanities
UX	User Experience
VET	Vocational Education and Training

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1. Introduction and state of art

1.1. Human-Centric Design in manufacturing

Human-Centric Design (HCD) represents the frontier in Industry 5.0, moving beyond purely technology-driven solutions to embrace user-driven approaches that integrate human, ethical, and societal factors. The ambition for progress centres on transforming the workforce and the intrinsic nature of work through effective Human-Machine Teaming. Advanced technologies (Digital Twins, AI, collaborative robots) profoundly impact the workforce, workspace, and the nature of work, creating new interactions between humans and machines, and between digital and physical worlds. The ambition is thus to move from simple automation to true HCD as guided by two key principles for high-value output:

1. Preserving and Enhancing Human Autonomy: Supporting the human without causing the operator to feel undervalued, lose motivation, or become "out-of-the-loop," which results in loss of Situation Awareness and the inability to take back control.
2. Designing Effective interactions: Focusing on interactions where the total output is better than either working alone, ensuring AI augments rather than simply replaces human roles.

In HARTU the integration of SSH methods was recognized as fundamental to achieving project goals, especially in addressing the non-technical challenges of AI/Robotics: transparency, trustworthiness, ethical responsibility, privacy, and the need for new workforce skills. SSH was used to explore and understand the specific production environment, analyze data to define AS-IS and TO-BE scenarios, and recommend changes related to upskilling, ethics, and acceptance.

Human centred design moves beyond assessment to co-creation and embedding values by design. Stakeholders and end-users are involved in a co-design work from the early stages to shape the definition and direction of the technology, creating a collaborative, discursive space between designers and users. HCD includes Ethics and Legal Cases to offer a structured approach for identifying, analyzing, and mitigating liability attribution issues (who holds responsibility for AI-based decisions) related to new operational concepts. Embedding values like fairness, equity, and justice involves identifying potential ethical harms, assessing training data biases, and monitoring compliance of the socio-technical system with fairness metrics. Focused tasks address the critical challenges of up-skilling, re-skilling, and mindset change required by the workforce due to automation. This involves defining new user profiles and creating Skills Transformation Maps to guide training and guarantee human well-being.

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1.2. State of the Art on Skills in Manufacturing

Starting from 2016-2018, the global manufacturing landscape started a profound transformation as a reaction to the limitations of Industry 4.0's purely technological focus. This transformation aims at moving beyond the efficiency-driven paradigm of Industry 4.0 towards Manufacturing 5.0 (or Industry 5.0), that places human-centricity, resilience, and sustainability [1] at the core of industrial production, fundamentally reshaping the required skill set for the future workforce. Studies, such as the one of Cimini et al [2], underlined the importance of the human element in Industry 4.0 already: as a development of Industry 4.0, industry 5.0 seeks a new collaboration model where human creativity and critical thinking are the core and not a post-operational element to be added.

This human-technology symbiosis necessitates the emergence of new roles and a corresponding need for widespread upskilling and reskilling initiatives across the sector. The future manufacturing worker must master a dual set of competencies, which are complementary:

1. **Technological and digital skills**: proficiency in core Industry 4.0 and 5.0 technologies such as collaborative robotics (cobots), Digital Twins, Industrial Internet of Things (IIoT) systems, Artificial Intelligence (AI), and advanced data analytics [3];
2. **Transversal and cognitive skills**: a heightened demand for uniquely human skills, including complex problem-solving, critical thinking, systems thinking, creativity, and effective communication and leadership [4]. These competencies allow workers to translate AI-driven insights into actionable strategies and handle the non-routine tasks that remain resistant to automation.

This technological and cultural shift creates a dynamic labour market where the supply of skills frequently lags behind the rapidly evolving employer demand. Addressing this gap requires new methodologies capable of identifying emerging skill needs with unprecedented speed and granularity.

Recognizing the crucial nature of this transition, European institutions have invested heavily in standardizing and collecting comprehensive labour market data, and funding projects specifically focused on the broad topic of skills. The output of this effort can be found in resources such as the European Skills, Competences, Qualifications and Occupations (ESCO) system [5], which provides a widely recognized, detailed occupational and skills classification; the European Centre for the Development of Vocational Training (Cedefop) [6] that develops a range of online tools, databases, and toolkits to provide evidence, analysis, and resources for policymakers, practitioners, and researchers in vocational education and training (VET) and skills; the Manufacturing Skills Observatory and Competencies Framework (ManuSkills) [7], a project aimed to develop a set of four tools that include (1.) the Manufacturing Competency Framework based on national curricula, industry expertise, and recommendations from organizations like ESCO, WMF, and WEF, (2) a mechanisms to Observe Future Skills Needs, (3) a Diagnostic Tool designed to derive individual

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competency profiles and (4) a Mechanism to Analyze Training Gaps and integrating these tools into the EIT Manufacturing Guided Learning Platform (Skills.move).
An analysis of the existing literature also revealed a positive trend in the development of sophisticated machine learning (ML) tools designed to tackle the inherent complexity of skill identification, both from the EU funded projects and academia. An example is TRAILS project [8], which stands for "TRAnsforming and Improvising Labour markets and Skills," a research and innovation project funded by the European Union's Horizon Europe program. The project focused on building on current data in skills mismatches and creating novel tools and databases, harnessing the power of Artificial Intelligence, with the goal to empower Vocational and Adult Education training to match employers with educational opportunities, efficiently reallocating workers. From the academia viewpoint, rapid advancements in Natural Language Processing (NLP) and deep learning techniques, such as BERT and Long Short-Term Memory (LSTM) networks, are being leveraged to extract, classify, and contextualize skills from massive repositories of unstructured text, like online job advertisements [9]. These data-driven methodologies allow researchers to autonomously generate objective skill taxonomies, using techniques like word embeddings (e.g., Word2vec) and network analysis to group co-occurring skills and capture semantic relationships between requirements, moving beyond traditional expert-derived models like ESCO and O*NET [10]. Furthermore, these automated techniques are being combined with technologies like Augmented Reality (AR) to provide adaptive support and measure tacit knowledge acquisition among factory operators [11]. These high-granularity, automated systems represent the cutting edge of labour market intelligence.
Despite the availability of rich foundational data from EU bodies and the sophistication of academic machine learning models, a critical operational gap persists: there is no readily available, universally usable tool that enables HR professionals and managers in the manufacturing sector to identify new roles and skill requirements by drawing on internal organizational knowledge and aligning with specific strategic objectives. Existing solutions are often overly complex, dependent on restrictive external Big Data sources, or lack a standardized framework for quantifiable comparison between worker capabilities and job requirements. Such complexity hinders adoption by non-specialists—particularly HR and production managers—who require intuitive, structured tools to support immediate training, reskilling, and workforce planning decisions.

To address these challenges, the HARTU project has developed an adaptable, human-in-the-loop framework designed to compare the as-is and the to-be scenario of manufacturing companies. The Skills Transformation Map framework guides users through a structured process that includes understanding current tasks, comparing them with future task requirements, defining the new working ecosystem, and identifying the skills needed to operate within it. By adopting a human-centred approach and incorporating a dataset of skills derived from real manufacturing pilots, the proposed model directly addresses the limitations of previous methods, making skills gap analysis both actionable and accessible across diverse organizational contexts.

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2. Methods

2.1. New roles and skills definition

To analyse the human impact of significant changes—such as the introduction of new technologies or the reallocation of tasks—on workers' skills, a structured procedure was adopted. Its purpose is to identify the skills required of human actors to operate effectively in the new working scenarios (TO-BE scenarios), and consequently determine the need for upskilling or reskilling.
The entire operational landscape—people, tasks, technologies, and required competencies, both before and after the change—was systematically mapped by answering four key questions:

1. Who is involved in the process?
2. What tasks are performed?
3. What technologies are used?
4. What competencies are needed?

Each of these four questions was answered for both the *AS-IS* and *TO-BE* scenarios to determine the precise nature of the change. The AS-IS analysis is needed to determine and document the current operational scenario, including the baseline human skills; while the TO-BE data, goes through all the aspects that might change and that are strongly related to the new skills required in the future working scenario.

2.2. Methods for a human-centred design in manufacturing

The methodology adopted for the development of the Human-Centred Design and Training Guidance within the HARTU project followed a structured, multi-stage approach designed to ensure that the resulting principles were theoretically robust, empirically grounded, and fully aligned with the operational realities of advanced manufacturing systems. The process integrated scientific evidence, stakeholder input, and targeted analytical activities, allowing the guidance to reflect both state-of-the-art knowledge and the practical requirements of the project's industrial use cases.

The first component consisted of in-depth evaluation of the context, including production processes and the working environment. Data collection activity from a Human Factors/SSH perspective was based on a framework defined in the project and considering various Human-Factors related categories and sub-categories. Six categories and sub-categories were identified as pertinent and included:

- **Working Environment:** The workspace, the general equipment and machinery used, and the

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physical environment

- **Organisation of work**: Organisational, production and people management within a work setting, consideration of personal and cultural factors and issues related to the management of organisational changes
- **Skills and Training:** The systematic development of competencies required by individuals to adequately perform their work
- **Roles, Procedures and responsibilities**: Actual/prescribed working methods, positions/functions in the organisation and expected tasks performed by relevant roles
- **Teams and communication**: How people work and communicate with each other on shared goals and tasks.
- **Human-machine interaction:** The actions, reactions, and interactions between humans and other system components.

In parallel to the study of the use cases, an extensive review of the scientific and technical literature on human-AI interaction was conducted. This systematic analysis established the conceptual foundation for the Human-AI Teaming Interaction Model (presented in D1.3). The review focused on identifying the critical factors, challenges, and design considerations associated with Human-Autonomy Teaming, Human-Robot Interaction, Human–Machine collaboration, and autonomous socio-technical systems. The literature selection was based on targeted keyword searches across the fields of human factors, artificial intelligence, computer science, and robotics, with priority given to recent publications while integrating earlier seminal works where relevant. This ensured a comprehensive and up-to-date theoretical basis for the model.

The second element involved translating theoretical insights into a coherent model structure, informed by an understanding of user needs, system requirements, and the envisioned TO-BE operational scenarios in manufacturing. Particular attention was given to the distribution of roles, responsibilities, and interactions between human operators and innovative systems, ensuring that the emerging model reflected the socio-technical complexity of the HARTU industrial environments.

A third component of the methodology focused on participatory validation through structured engagement with the consortium. Focus group sessions were organised to gather input from all partners, discuss internal acceptability criteria, and align the model with the constraints, expectations, and priorities of the project stakeholders. This participatory phase ensured that the resulting guidance would be relevant, implementable, and consistent with the specificities of the HARTU use cases.

Finally, a dedicated survey was used to collect data on key interaction factors, while a workshop on role allocation strategies was conducted to analyse desirable and undesirable configurations of human and AI roles within the use cases. These activities enabled a deeper contextualisation of the model and supported the transformation of conceptual insights into concrete and operational Human-Centred Design principles.

Through this integrated methodology combining theoretical analysis, contextual interpretation, and participatory validation the project produced a set of Human-Centred Design guidance that is

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scientifically grounded, operationally meaningful, and directly applicable to the design of future manufacturing scenarios.

3. Skills Transformation Map

The Skills Transformation Map is an interactive tool designed to easily visualize and navigate the results of the skill analysis conducted starting from the HARTU use cases. The tool allows the design team to visualize the identified new human profiles, along with their related skills and tasks.
First, the data have been translated into intuitive charts, designed to guide the reading of the data according to the specific aspects investigated (e.g., the characteristics of a specific worker profile or the main skill categories required in the TO-BE scenarios). In particular, the tool displays a comparison between the AS-IS and TO-BE scenario data, highlighting the gap between the two working setups. The latter represent a fundamental starting point for any manufacturing project approaching a redesign of the working environment (e.g., the introduction of a new technology such as a collaborative robot). Moreover, the available filters support data navigation and tailored exploration according to user needs.

The first step in designing the tool consisted in identifying a clear way to visually translate the data through effective graphical representations.

Skills Transformation Map design

The structure, data organization, graphic visualization choices, and the User eXperience (UX) during the tool navigation have been specially studied.
The transformation map is designed as a digitally consultable tool organized into independent thematic sections. Navigation is guaranteed by a horizontal menu, constantly visible in the lower section of the screen, which allows direct switching between the main sections: Tasks, Skills, Roles, Guidance.

- **Roles** - This section shows the three introductory cards of the TO-BE roles and the relationship with the AS-IS roles, providing an immediate view of the transformation process (Figure 1).
  The AS-IS roles that converge into the new profiles are reported in the upper part of each card. These elements are represented as coloured rectangles, each connected by a line to the card of the corresponding TO-BE profile. The objective is to make it evident how multiple existing roles are incorporated and transformed into a single simplified and updated profile. The latter are differentiated by three distinct colours (i.e., light blue for the Smart Line Operator, orange for the Plant Flow-Keeper, and blue for the Tech Solver), chosen based on the HARTU palette. This choice serves to ensure immediate recognition of

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the roles throughout the Transformation Map.
Each role is represented by a dedicated card, structured in a consistent and repetitive way to create familiarity and readability, showing: Role Name, Identifying Icon, Synthetic Description, Summary of the main skills and tasks. This synthetic representation offers an immediate perception of the role's nature at a glance, without requiring the analysis of the other more detailed sections.

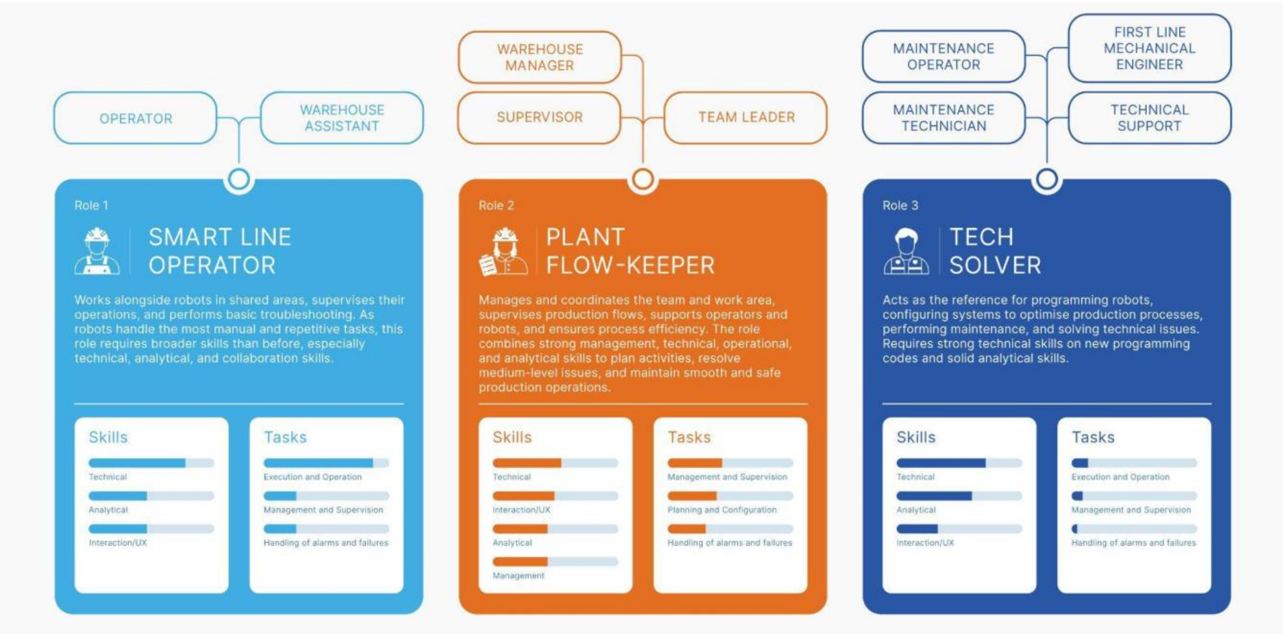

Figure 1. Skills Transformation Map - AS-IS human role transformation into the three new profiles

- **Skills** - This page allows consulting the mapping of skill categories required for each role both in the TO-BE and AS-IS scenarios (Figure 2) .
  The chart presents the three TO-BE roles' icons arranged vertically at the centre of a radial visualization composed of three concentric circles, each associated with a TO-BE profile: first circle dedicated to the Smart Line Operator, second circle for the Plant Flow Keeper, and the third circle dedicated to the Tech Solver).
  All the three circles are subdivided into seven segments, one for each skill category: Technical, Operational, Analytical, Collaboration/Communication, Management, Personal/Soft, Interaction/UX. This subdivision allows each category to be read as a **radial histogram** showing the distribution of skills required for each role.
  The icons of the three TO-BE roles are clickable, serving as a filter to visualize only the data of the selected profile. At the same time, a side bar on the right appear showing the role card to provide an overview of the role charactering and in this way facilitating the data understanding.

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Also the skills category names are clickable allowing a visualization switch into an exploded mode (Figure 3). This is a more detailed chart showing each specific skill maintaining the same radial structure and circle-roles association. Each skill is represented by a dot and a descriptive label. This visualization indicates the presence or absence of each skill for every role through a coloured dot matching the role's colour.
Clicking on the AS-IS button on the top left, a layer showing the data of the AS-IS scenario overlaps the TO-BE chart. The AS-IS data are reported on the same radial segments, and represented by a white border. This visualization allows for an immediate comparison between the coloured filling (TO-BE) and the white border (AS-IS) for each segment and for each role.

- **Tasks** - This section shows the task categories required for each role in the TO-BE and AS-IS scenarios, considering also the "nature" of the tasks. As for the skills chart, the roles' icons are placed at the centre of a radial chart with three circles (i.e., the innermost circle represents the Smart Line Operator, middle circle represents the Plant Flow-Keeper, and the outermost the Tech Solver) divided in three sections representing the task nature (i.e., human, robot, shared).
  As shown in Figure 4, coloured bars representing the percentage of tasks performed by each role for each specific category, are present along the role circumferences and divided by the task nature. Each task category has been associated with a colour as follows: green for *Planning and Configuration*, yellow for *Execution and Operation*, blue for *Management and Supervision*, red for *Collaboration and Assistance*, pink for *Quality Control*, brown for *Handling of Alarms and Failures*.
  Clicking the roles' icons it is possible to visualize the data of a specific role, while clicking a category (e.g., Quality Control) displays only the bars belonging to that category, for all three roles, while the other categories are hidden.
  As with the skills, the AS-IS filter, shows the percentage of task categories overlapped to the TO-BE data. To ensure good readability, the TO-BE data become darker, as they are under the filter, and the AS-IS data are bright coloured bars with a white outline.
- **Guidance** - This page provides the list of the Human-Centred Design and Training guidelines (Figure 5). The guidelines are organised into two distinct sections, allowing users to navigate each part independently according to their specific interests. Convenient collapsible menus provide an overview of all sections and guidelines that make up the Human-Centric Design and Training Guidance. Depending on the desired level of detail, users can expand the main guidelines and display the corresponding sub-guidelines only for the sections they wish to explore.
  The full and detailed description of all guidelines is presented in Chapter 4.

The specific pages and charts designed and included in the Skills Transformation Map are described below. The interactive prototype can be accessed and navigated at this link: https://www.figma.com/proto/qNpE5vB0Gc3W06U67VrdXv/Skills-Transformation-Map---

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interattivo?node-id=2626-13701&p=f&t=sQoX3o19utQ4ToI8-1&scaling=contain&content-scaling=fixed&page-id=2626%3A460&starting-point-node-id=2626%3A13701

Figure 2. Skills Transformation Map – Skills chart for the TO-BE (top) and AS-IS (bottom) scenarios

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Figure 3. Skills Transformation Map – Required skills for each human profile in the TO-BE scenario

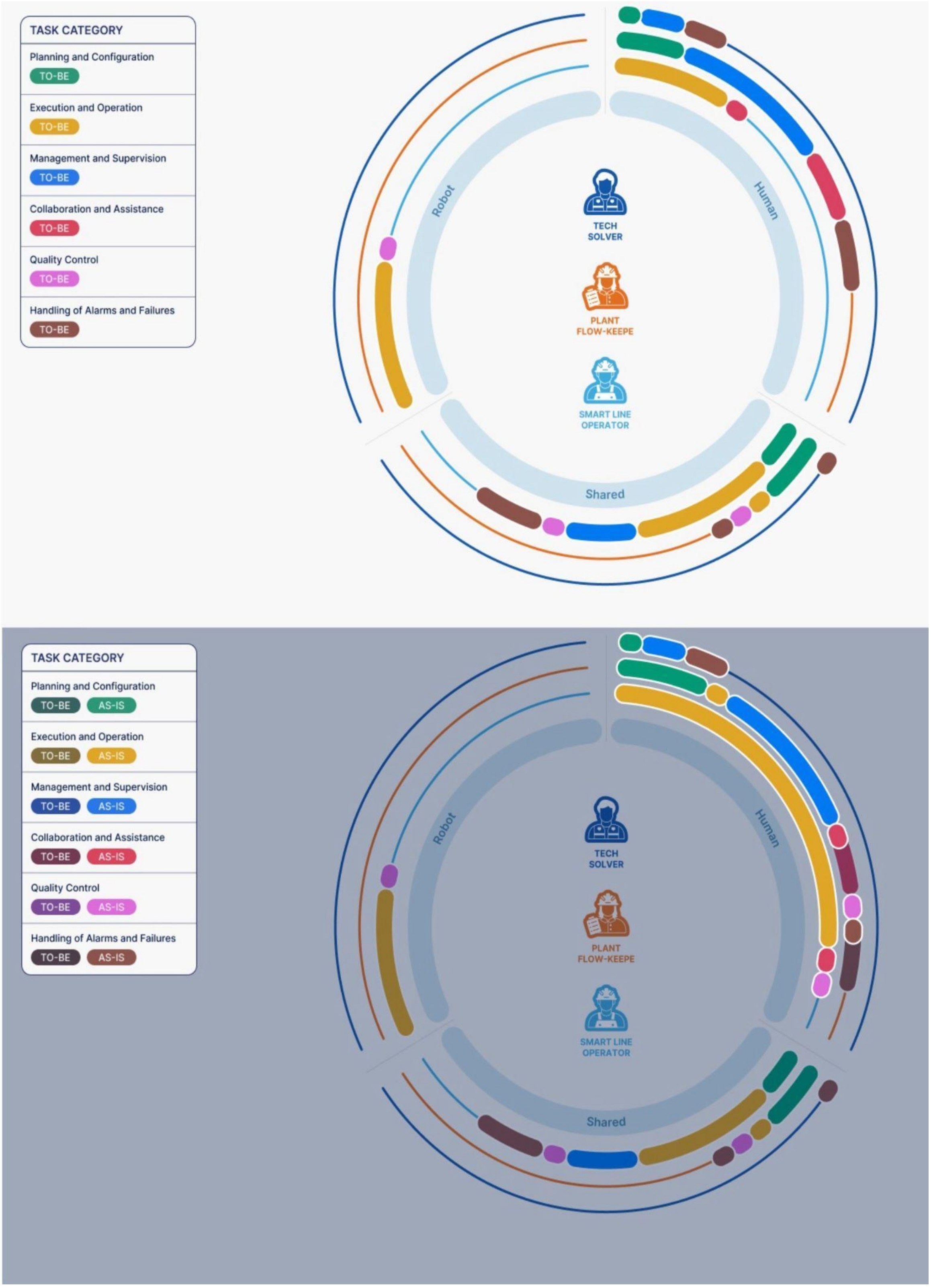

Figure 4. Skills Transformation Map – Tasks chart for the TO-BE (top) and AS-IS (bottom) scenarios

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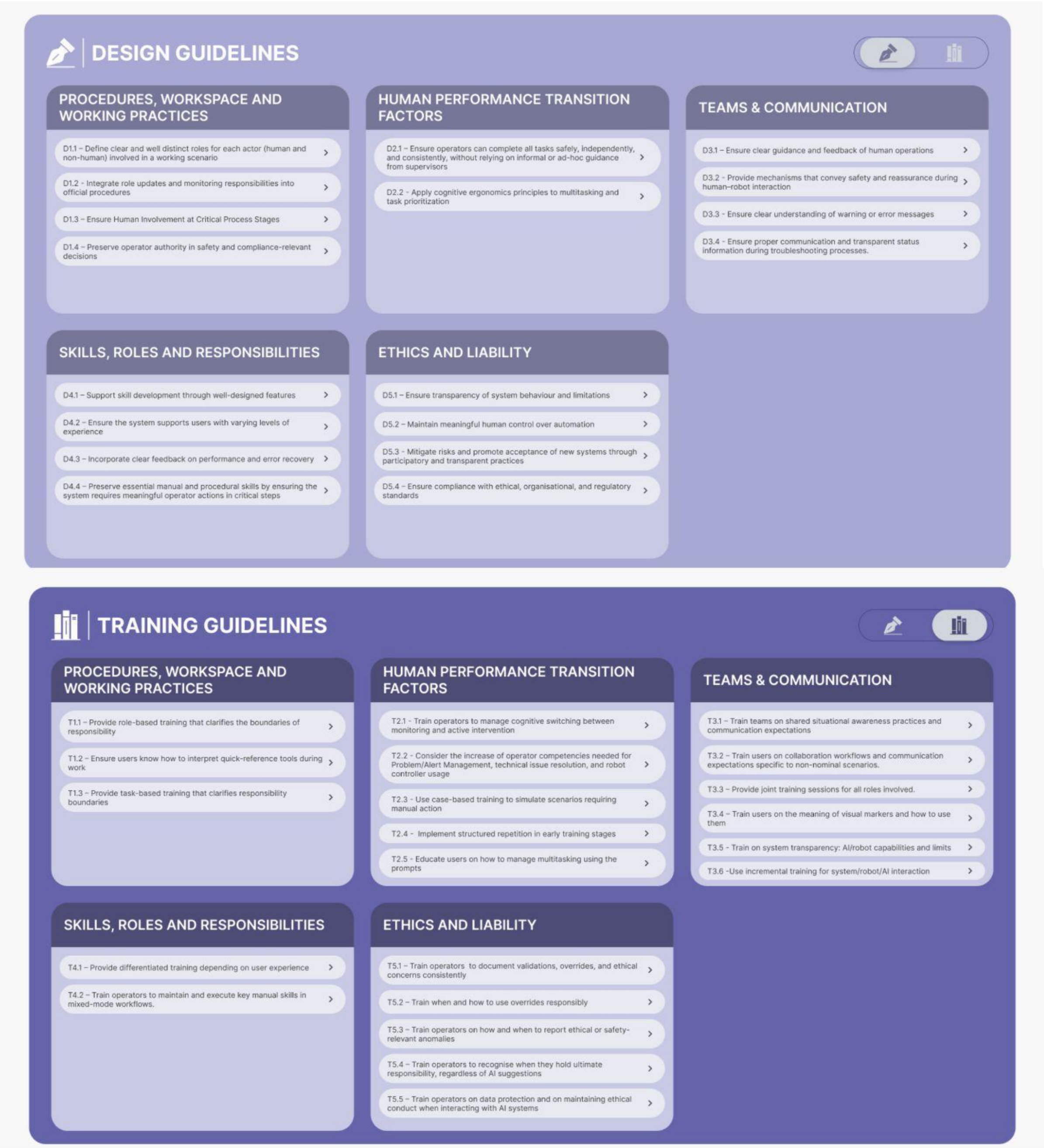

Figure 5. Design (top) and Training (bottom) guidelines

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3.1. New human profiles

Starting from the structured analysis developed for each use case, an in-depth analysis of the transformation of human roles—both in terms of tasks to be performed and required skills—was conducted. As a result, three main new human profiles were identified: *Smart Line Operator, Plant Flow Keeper, and Tech Solver*. These profiles are valid across all the use cases and not strictly tied to any single scenario. Indeed, they are intended to be key-reference roles that represent the transformation human actors will undergo in Industry 5.0 contexts.

Specifically, they are described as follow:

- The *Smart line operator* works alongside robots in shared areas, closely supervising their operations, and performing basic troubleshooting. As robots handle the most manual and repetitive tasks, this role requires broader skills than it used to, especially related to technical, analytical, and collaboration competencies. When troubleshooting is more complex than expected, this role escalates to the Plant-Flow Keeper who is their point of reference.
- The *Plant Flow Keeper* manages and coordinates the team and working area, supervises and monitors production flows, supporting operators and robots upon request, and ensuring process efficiency. The role combines strong managerial, technical, operational, and analytical skills and knowledge, needed to to plan activities, solve medium-level issues, and maintain smooth and safe production operations.
- The *Tech Solver* is the referral point for technical tasks related to tech systems. Their knowledge can span from the programming of robots/sensors/AI,to their configuration and settings, and the optimisation of production processes, performing maintenance (preventive and prescriptive), and solving technical issues. This role requires strong technical skills and solid analytical skills.

As shown in Figure 1, each human role mapped in the AS-IS scenarios of the HARTU use case are traced back to the new profiles. Specifically: the roles called *Operator* and *Warehouse Assistant* in the AS-IS scenarios are transformed into the *Smart Line Operator* profile; the roles *Warehouse Manager, Supervisor,* and *Team Leader* in the AS-IS scenarios correspond to the new *Plant Flow Keeper* profile; finally, the AS-IS roles *Maintenance Operator, Maintenance Technician, First Line Mechanical Engineer, and Technical Support* correspond to the new profile *Tech Solver*.

3.2. List of human skills

The first step in defining the skills required for the TO-BE scenarios consisted of creating a representative list of skills covering the main responsibilities an operator would have. This approach allowed, starting from the analysis of the tasks to be performed by operators, as well as

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the types of technologies and workspace conditions, a systematic identification of the necessary skills.

As with the defined profiles, the purpose behind developing the skills database was to create a general-purpose tool, capable of fitting any operator profile in an Industry 5.0 scenario. An initial version of the skills database was developed based on a literature review and expert-based analyses of the Industry 5.0 case studies. Subsequently, the dataset was refined and expanded during workshop sessions conducted for each use case (each lasting approximately 1.5 hours), incorporating significant input from the participating partners. The final version of the skills dataset is presented in Table 1.

Table 1. Skill list

Skills Category	**Sub-category**	**Skills**
Technical Skills Identify technical skills necessary for the implementation and use of the technology. Skills related to the day-to-day operation and maintenance of the technology.	**GENERAL**	• Technical issues resolution • Digital systems usage • Digital data management • System state interpretation • Technical inspection • Problem / Alert management • Algorithms output understanding • Quality assessment • Setting up the activity • Statistical process control • Understanding AI systems • Data processing • Coding
	MACHINE	• Knowledge of Machine/Robot task • Machine/Robot maintenance • Machine/Robot setting parameters • Turning on machines/robot
	ROBOT	• Use of the Robot controller • Understanding the Robot coding/language • Knowledge of robot mechanisms • Setting up the robot • Robot programming • Understand the robot feedback
	TASK-RELATED SKILLS	• Deburring • Scanning • Fly the drone • Robot Trajectory revision • Operating mobile plant • Driving vehicles • Monitor moving workpiece in a machine
		• Procedures knowledge of error situation

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Operational Skills The skills needed to manage everyday tasks and ensure that things run smoothly within an organization.	**GENERAL**	• Process awareness • Task knowledge • Time management • Coping with pressure • Situational awareness • Fast task execution • Procedures knowledge • Handling unexpected events and emergencies
Analytical Skills The skills needed to think critically, solve problems, and make decisions by understanding and analysing information.	**GENERAL**	• Problem solving • Data interpretation • Decision Making • Making time-critical decisions • Problem identification • Predictive maintenance • Preventive maintenance
Collaboration and Communication Skills The skills needed to work well with others, share ideas clearly, listen actively, and solve problems together.	**GENERAL**	• Revising algorithm's suggestion • Digital System/Machine/Robot automatic reports understanding • Coordination across operators • Coordination with the robot work • Assisting others in complex situations
	HUMAN-AI TEAMING	• Understand AI-generated insights • Provide feedback to AI systems • Assign and manage tasks • Avoid collision with AI
Management Skills The skills needed to plan, organize, and lead a team or project to achieve goals and meet deadlines.	**GENERAL**	• Task/Production planning • Conflict resolution • Team management • Supervising staff
	SAFETY MANAGEMENT	• Risk assessment • Safety checking • Monitoring workers' safety on the production floor • Monitoring security procedures in warehouse operations
Personal/Soft skills Personal qualities that help interact well with others and handle challenges.	**GENERAL**	• Responsiveness • Manual Dexterity • Observation skills • Dealing with challenging and stressful work conditions • Physical strength • Adapting to changing situations • Meet commitments (e.g., working plan and deadlines)
Interaction Skills The skills needed to efficiently interact with products, technologies or services.	**GENERAL**	• Navigate and operate touchscreen-based interfaces • Utilize AR devices (such as smart glasses or tablets) to receive real-time, step-by-step assembly instructions and visual guidance • Production monitoring • Use voice commands to start, stop, or adjust machinery without physical interaction

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		• Collaborate with robotic systems in shared workspaces • Use gesture-based controls • Respond to haptic (vibration) signals or tactile feedback • Interact physically with cobots
Ethics Skills The skills needed to understand and follow moral principles, making decisions that are fair, responsible, and respectful of others.	**GENERAL**	• Apply ethical principles • Promote ethical behaviour • Evaluate ethical implications • Ensure data ethics

The identified associations between human profiles and skills were then studied, visually represented, and included in the Skill Transformation Map (Figure 2-3). As shown in Figure 6, comparing the data across the human profiles and the TO-BE and AS-IS scenarios allows to make several observations that address the following key questions.

How do skills change from the as-is to the to-be scenario? (Figure 6)

In general:
- Technical skills, Interaction/UX skills, and Analytical skills increase;
- Personal/Soft skills and Collaboration/Communication skills decrease.

Smart Line Operator:
- Technical and Analytical skills increase significantly;
- Interaction/UX skills and Management skills introduced;
- Operational skills decrease considerably.

Plant Flow Keeper:
- Technical skills increase significantly;
- Management and Collaboration/Communication skills decrease slightly;
- Interaction/UX skills introduced.

Tech Solver:
- Interaction/UX skills increase greatly;
- Technical, Operational and Analytical skills increase slightly.

What skills are the most required? (Figure 3)

In general:
- Technical issues resolution;
- Problem/Alert management;
- Use of the robot controller;
- Understand the robot controller;

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- Know how to interact with robots;

Smart Line Operator:
- Technical skills: Technical issues resolution; Problem/Alert management; Quality assessment; Quality assessment, Setting up the activity, knowledge of machine/robot tasks, machine/robot setting parameters, Use of robot controller, Understand the robot feedback, know how to interact with robots;
- Operational skills: Task knowledge, Coping with pressure, Situational awareness;
- Analytical skills: Problem identification;
- Collaboration/Communication skills: Coordinating across operators, Coordinating with the robot work;
- Management skills: Safety checking;
- Personal/Soft skills: Responsiveness, Manual Dexterity, Adapting to changing situations;
- Interaction/UX skills: Use of touchscreen-based interface, Collaborating with robots in shared spaces, Use gesture-based controls, Use of production monitoring dashboard, Use voice commands;

Plant Flow Keeper:
- Technical skills: Process awareness, Technical issues resolution, System state interpretation, Problem/Alert management, Setting up the activity, Knowledge of Machine/Robot task, Turning on machines/robot, Use of the Robot controller, Understand the robot feedback, Know how to interact with robots;
- Operational skills: Procedures knowledge of error situation, Task knowledge, Fast task execution, Handling unexpected events and emergencies;
- Analytical skills: Problem-solving, Data interpretation, Decision Making, Risk assessment;
- Collaboration/Communication skills: Assisting others in complex situations;
- Management skills: Task/Production planning, Conflict resolution, Team management, Supervising staff, Safety checking, Monitoring workers' safety on the production floor, Monitoring warehouse security procedures;
- Personal/Soft skills: /
- Interaction/UX skills: Use of production monitoring dashboard.

Tech Solver:
- Technical skills: Technical issues resolution, Technical inspection, Problem/Alert management, Algorithms output understanding, Data processing, Machine/Robot maintenance, Machine/Robot setting parameters, Use of the Robot controller, Understanding the Robot coding/language, Knowledge of robot mechanisms, Setting up the robot, Robot programming, Understand the robot feedback, Know how to interact with robots, General programming;
- Operational skills: /
- Analytical skills: Problem-solving, Data interpretation, Problem identification, Preventive maintenance;

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- Collaboration/Communication skills: /
- Management skills: Safety checking;
- Personal/Soft skills: /
- Interaction/UX skills: /

What are the changes across the skill categories from the as-is to the to-be scenario? (Figure 6)

- Technical skills: increased for all the three profiles;
- Operational skills: decreased for all the three profiles;
- Analytical skills: increased for the Smart Line Operator and Tech Solver, unchanged for the Plant Flow Keeper;
- Collaboration/Communication skills: decreased for the Smart Line Operator and Plant Flow Keeper, unchanged for the Tech Solver;
- Management skills: introduced for the Smart Line Operator, decreased for the Plant Flow Keeper, not required for the Tech Solver;
- Personal/Soft skills: decreased for the Smart Line Operator and Plant Flow Keeper, not required for the Tech Solver;
- Interaction/UX skills: increased for all three roles.

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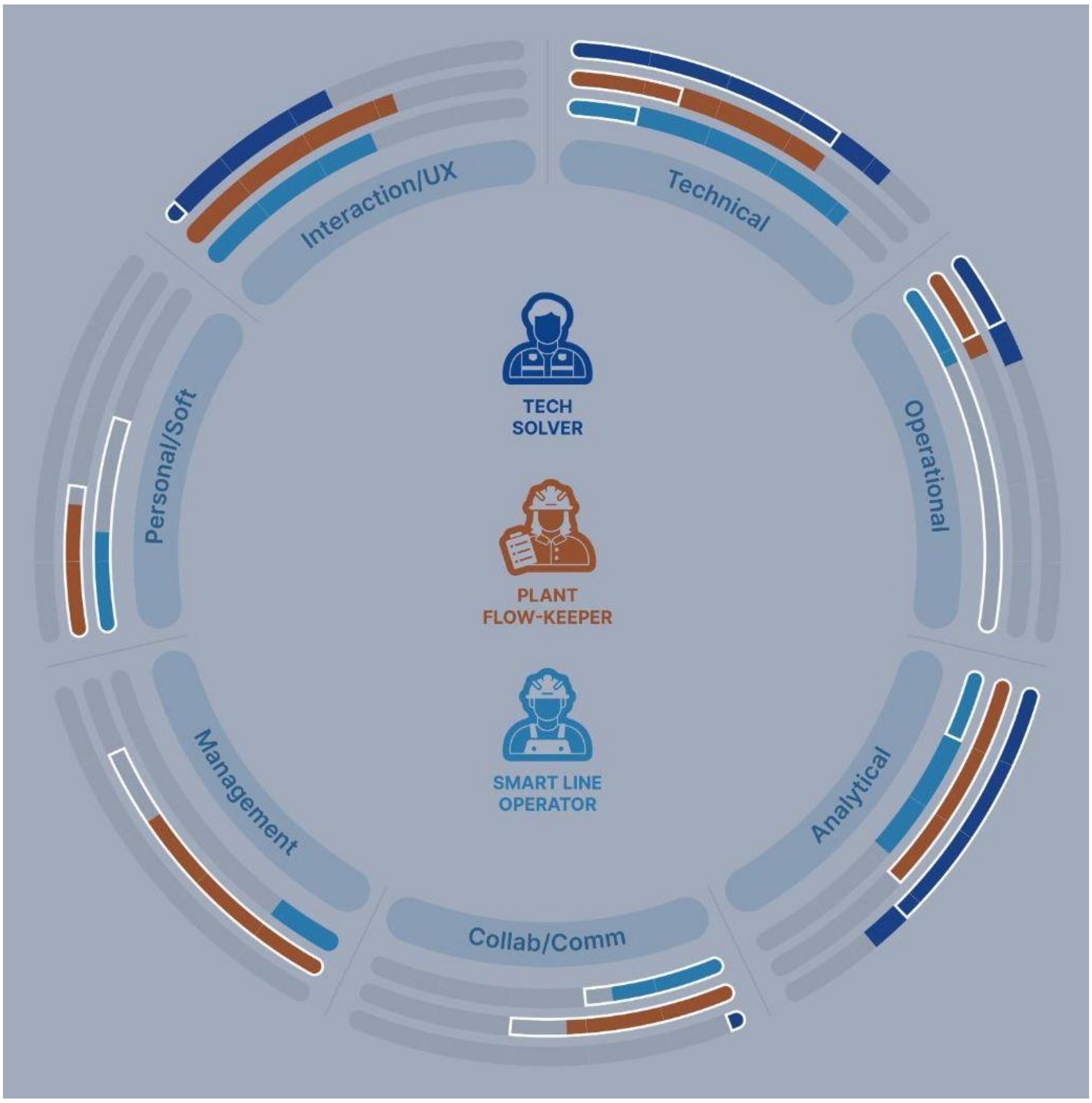

Figure 6. Skills Transformation Map - Percentage of skill categories required for each human profile in the AS-IS scenario (white outline) and the TO-BE scenario (coloured filled lines)

3.3. List of human tasks

To provide a clearer understanding of the required skills, it was considered appropriate to explore how tasks are allocated among the involved actors (e.g., operators, robots). For this purpose, each task in the HARTU use cases was associated with a defined task category (i.e., *Planning and Configuration, Execution and Operation, Management and Supervision, Collaboration and Assistance, Quality control, Handling of Alarms and Failures*). Figure 7 shows a percentage-based representation of the task types associated with each profile.

A specific analysis was carried out to understand how the distribution of tasks changes among the different actors involved in the TO-BE scenarios, distinguishing between those performed solely by

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human operators, those performed solely by the robot (or implemented technologies), and — as a new possibility — those shared or jointly executed by both actors. Indeed, contrary to expectations, and as shown in Figures 7 and 8, in the TO-BE scenarios humans do not experience a reduction in the number of tasks performed. Rather, a significant portion of the tasks will now require simultaneous execution or close coordination with the tasks performed by the robot/new technology.

Following this analysis, the questions below were answered.

How do tasks distribution change from the as-is to the to-be scenario? (Figure 7-8)

In general:
- Shared tasks with the robot/technology increase.
- The number of tasks increases for all three roles.

Smart Line Operator:
- Tasks performed solely by the human decrease.
- Many shared tasks with the robot emerge.
- New tasks assigned exclusively to the robot appear.

Plant Flow Keeper:
- Tasks performed solely by the human increase slightly.
- Some new shared tasks with the robot emerge.

Tech Solver:
- Tasks performed solely by the human remain unchanged.
- One new shared task with the robot emerges.

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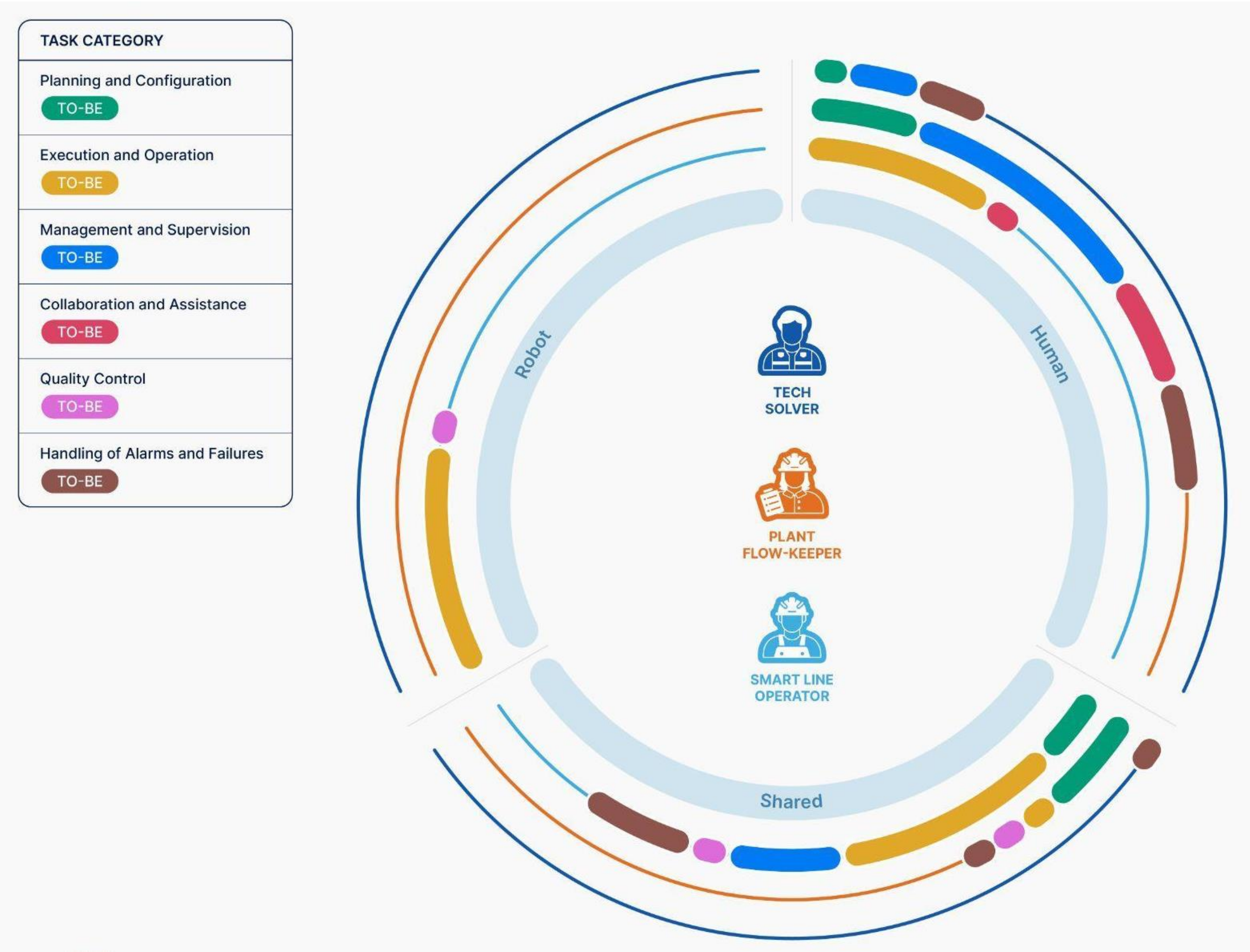

Figure 7. Skills Transformation Map - Task distribution for each human profile in the TO-BE scenario

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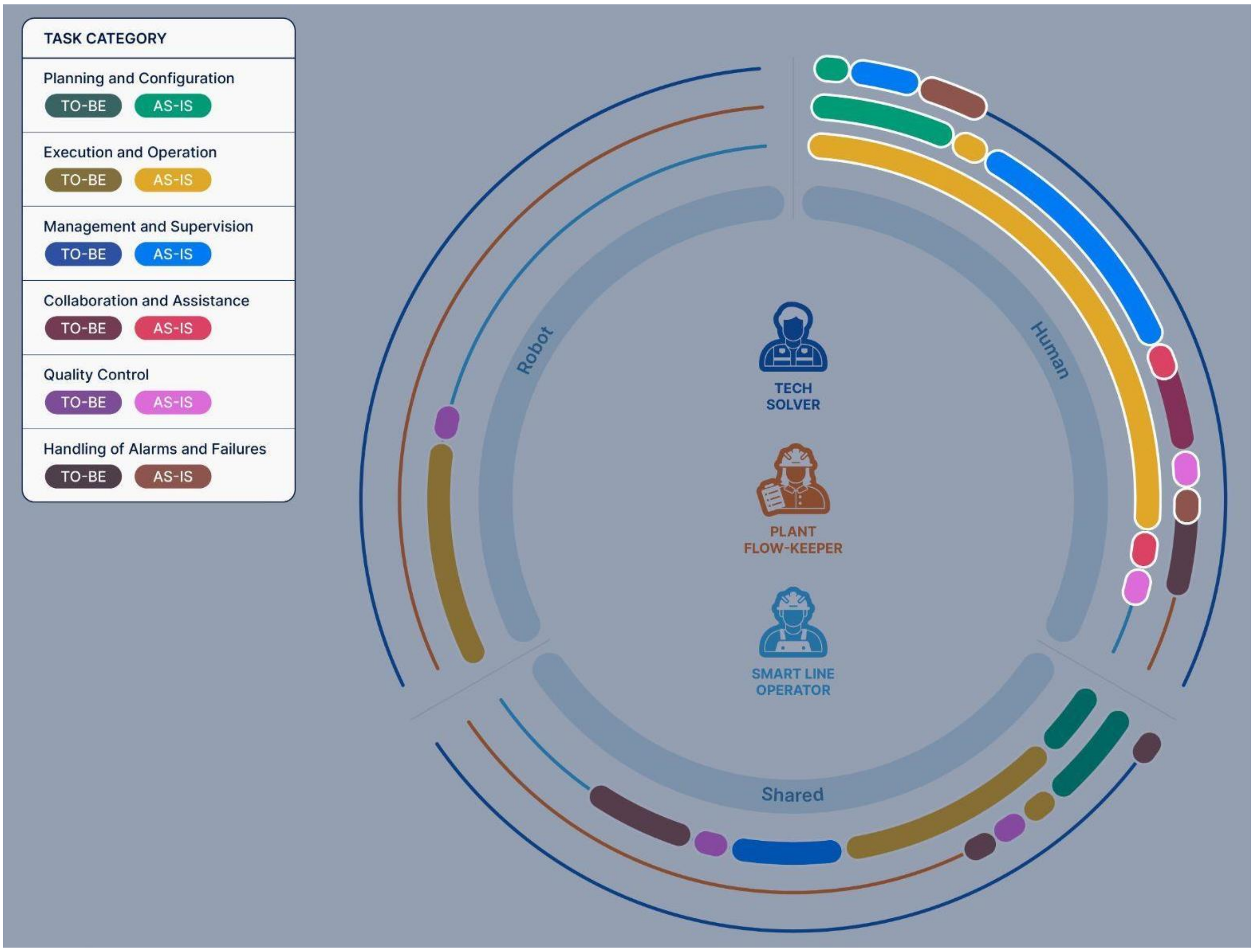

Figure 8. Skills Transformation Map -Task distribution for each human profile in the AS-IS scenario

What are the main changes in the types of tasks between the as-is and to-be scenarios? (Figure 4)

<u>In general:</u>

- Planning and Configuration tasks increase, especially as shared activities
- Execution and Operation tasks increase slightly, shifting from human-only tasks to shared or robot-responsible ones
- Management and Supervision tasks increase
- Quality Control tasks increase as shared activities
- Handling of Alarms tasks increase as shared activities

<u>For Smart Line Operator:</u>

- New shared Planning and Configuration tasks introduced
- Human-only Execution and Operation tasks decrease, becoming mostly shared or robot-responsible
- New shared Management and Supervision tasks introduced
- New shared Quality Control activities introduced

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For Plant Flow Keeper:
- Execution and Operation becomes a shared task
- Increase in shared Planning and Configuration tasks
- Increase in human-only Management and Supervision tasks
- Handling of Alarms and Failures becomes a shared activity

For Tech Solver:
- A new shared Quality Control task introduced

What are the changes across the task categories from the as-is to the to-be scenario? (an example is shown in Figure 9)

Planning and configuration:
- Increase for the Plant Flow Keeper
- Introduced for the Smart Line Operator
- Remain unchanged for the Tech Solver

Execution and Operation:
- Decrease for the Smart Line Operator, as these tasks are now mainly performed by the robot
- For the Plant Flow Keeper, the number of tasks remains the same, but they become shared rather than human-only

Management and Supervision:
- Introduced for the Smart Line Operator
- Increase for the Plant Flow Keeper
- Remain unchanged for the Tech Solver

Collaboration and Assistance:
- Introduced for the Smart Line Operator
- Remain unchanged for the Plant Flow Keeper
- Not present for the Tech Solver

Quality Control:
- Introduced as shared activities for the Smart Line Operator
- Increase for the Plant Flow Keeper
- Increase in shared activities for the Tech Solver

Handling of Alarms and Failures:
- Increase as shared activities for both the Smart Line Operator and the Plant Flow Keeper

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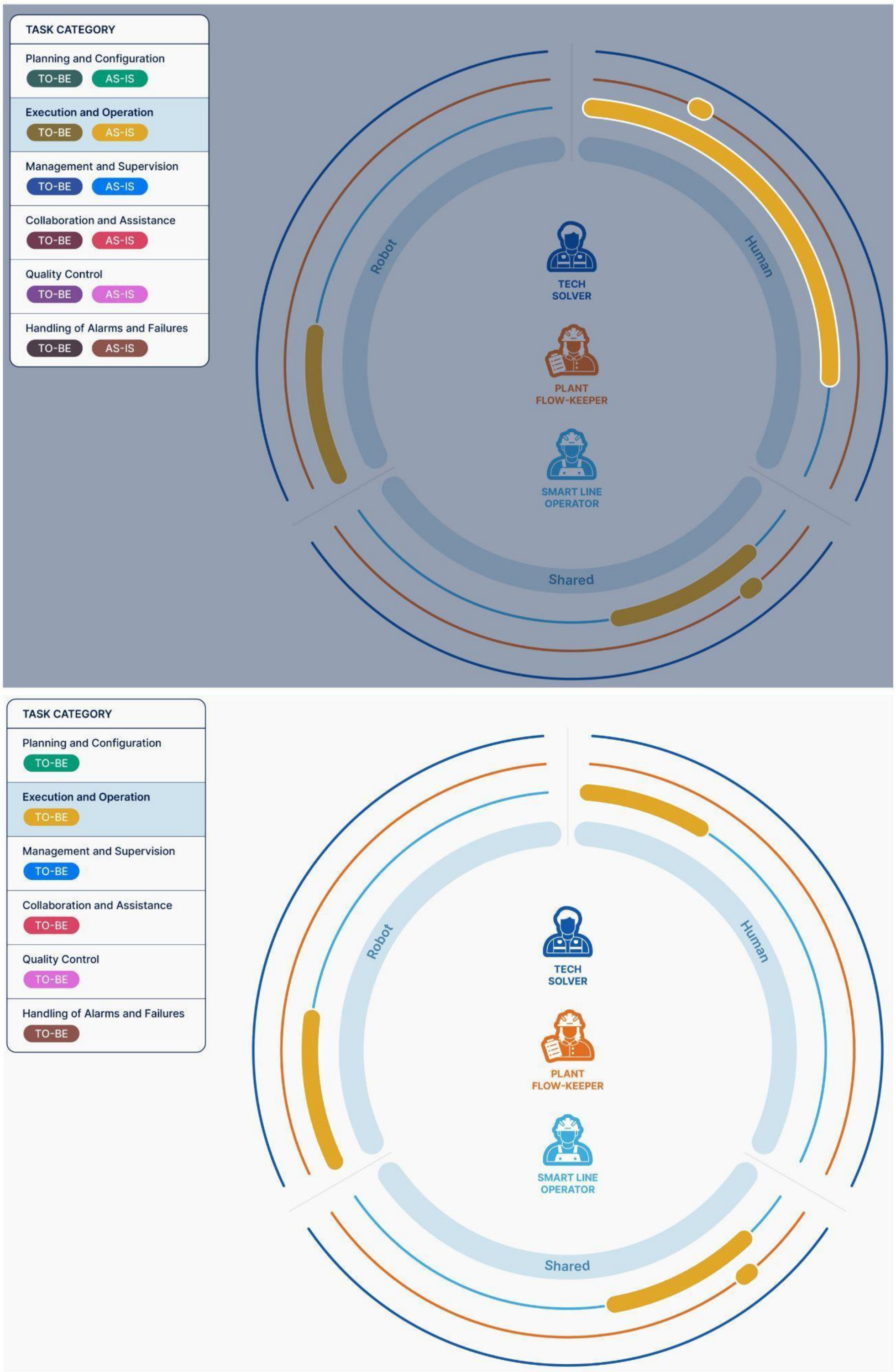

Figure 9. Skills Transformation Map - Percentage of tasks performed by the new profiles in the AS-IS (top) and TO-BE (bottom) scenarios

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3.4. Skills Transformation Map application to the use cases

3.4.1. TCA

In the TCA use case the three human operators assumed the new roles of Smart Line Operator and Plant Flow-Keeper (Figure 10). As a new team mate, the Robotic System is in charge of the specific task of sorting vegetables phase, as shown in Figure 11.

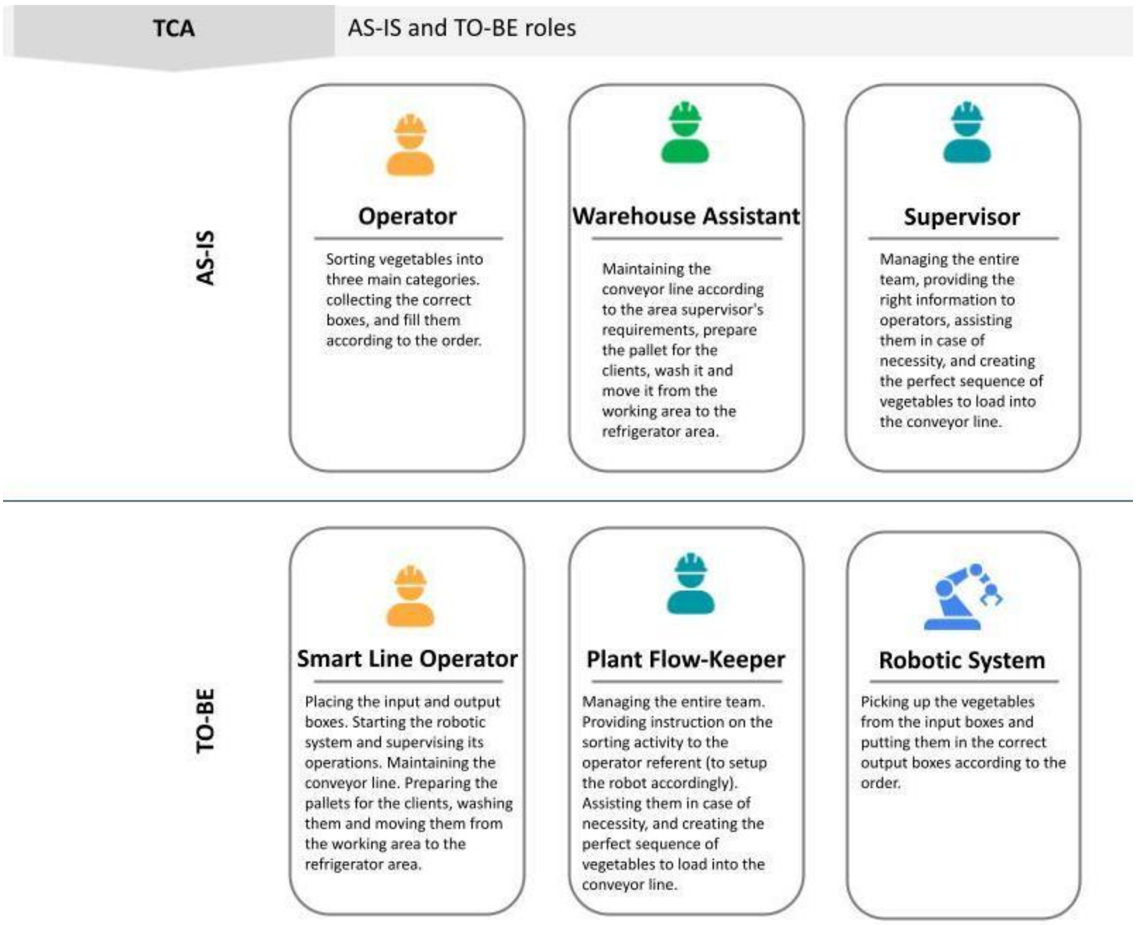

Figure 10. Roles transformation in the TCA use case

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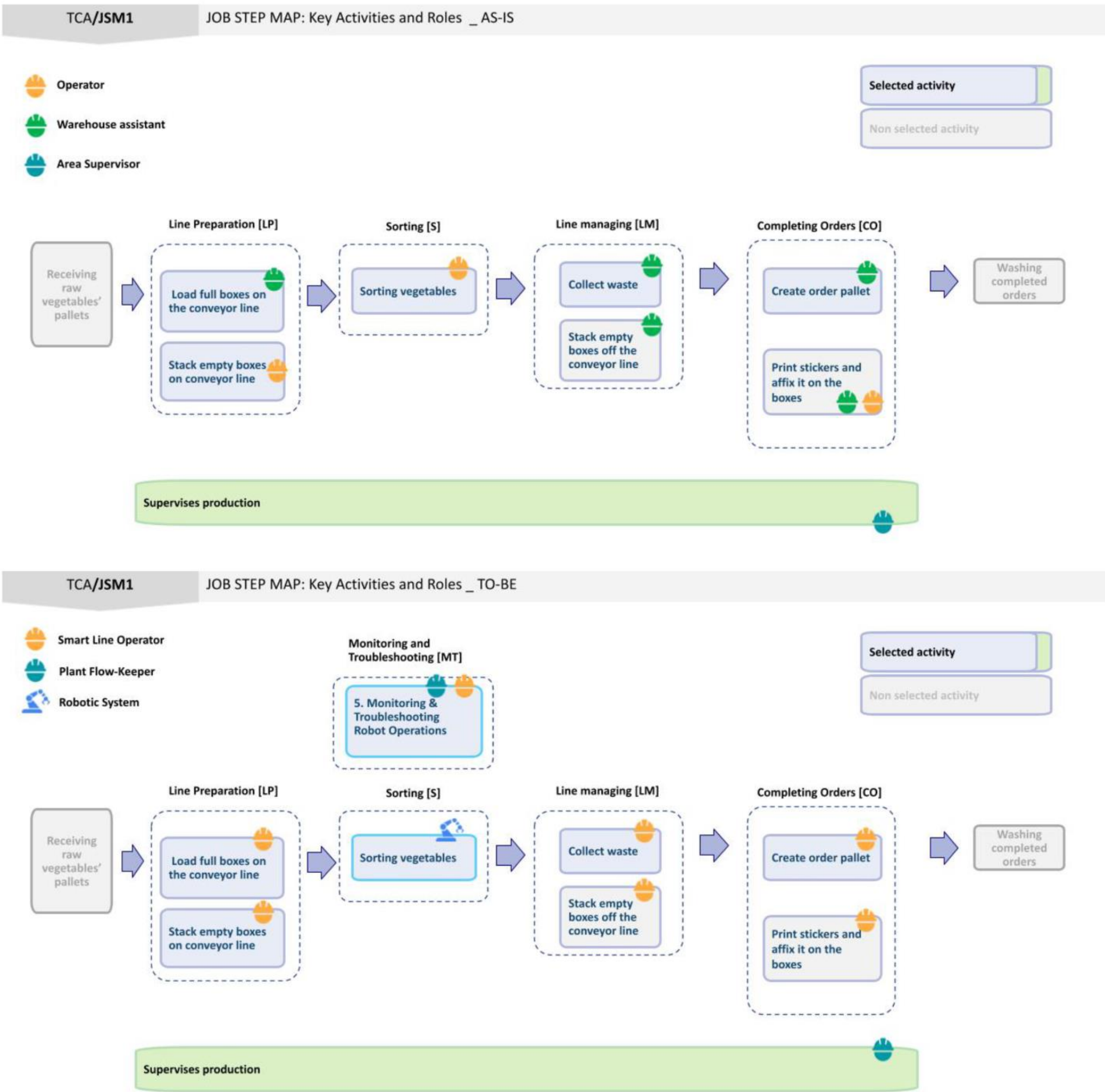

Figure 11. Job Step Map transformation of the as-is (above) and to-be (below) scenarios in the TCA use case

3.4.2. PCL

In the PCL use case, in the AS-IS scenario many operators are involved. In the TO-BE scenario transformation, the Assembly operator assumes the Smart Line Operator role, the Team Leader and the Quality Leader are represented by the Plant Flow Keeper profile, while the Maintenance Operator, the First Line Mechanical engineer and the Technical Support are associated with the Tech Solver profile (Figure 12). As new team mate, these operators share the workspace with a

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robotic system for the Racking unlacquered parts on the jigs and Unloading of lacquered parts steps (Figure 13).

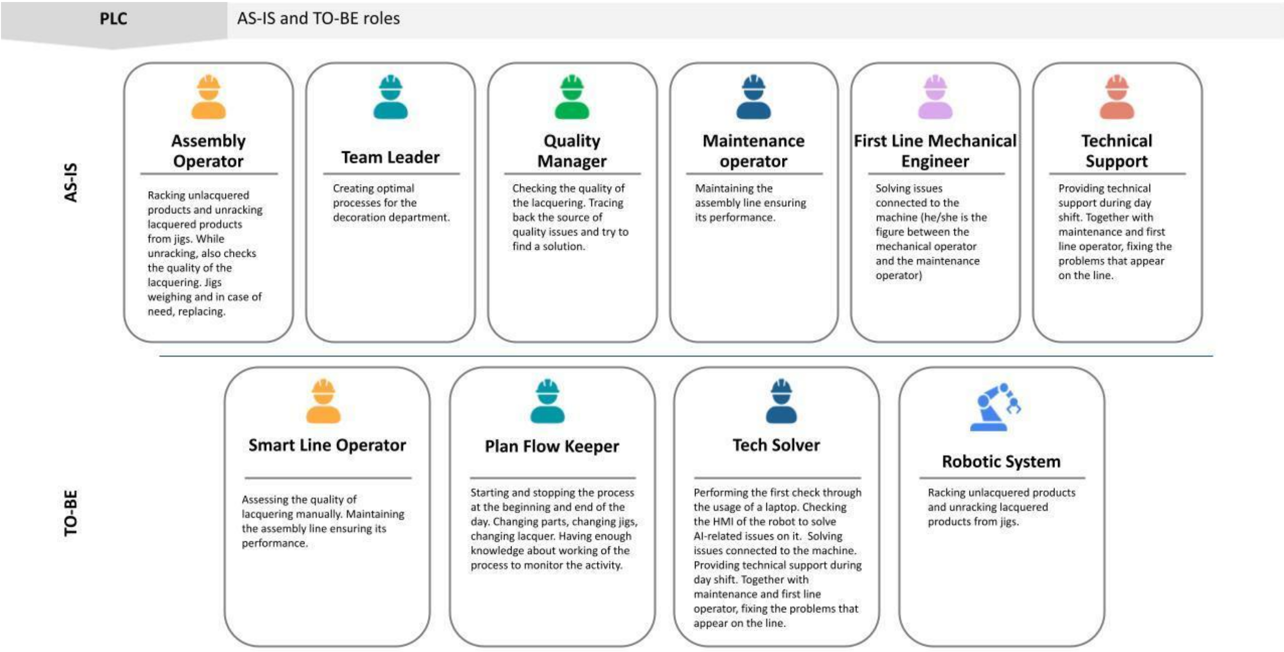

Figure 12. Roles transformation in the PCL use case

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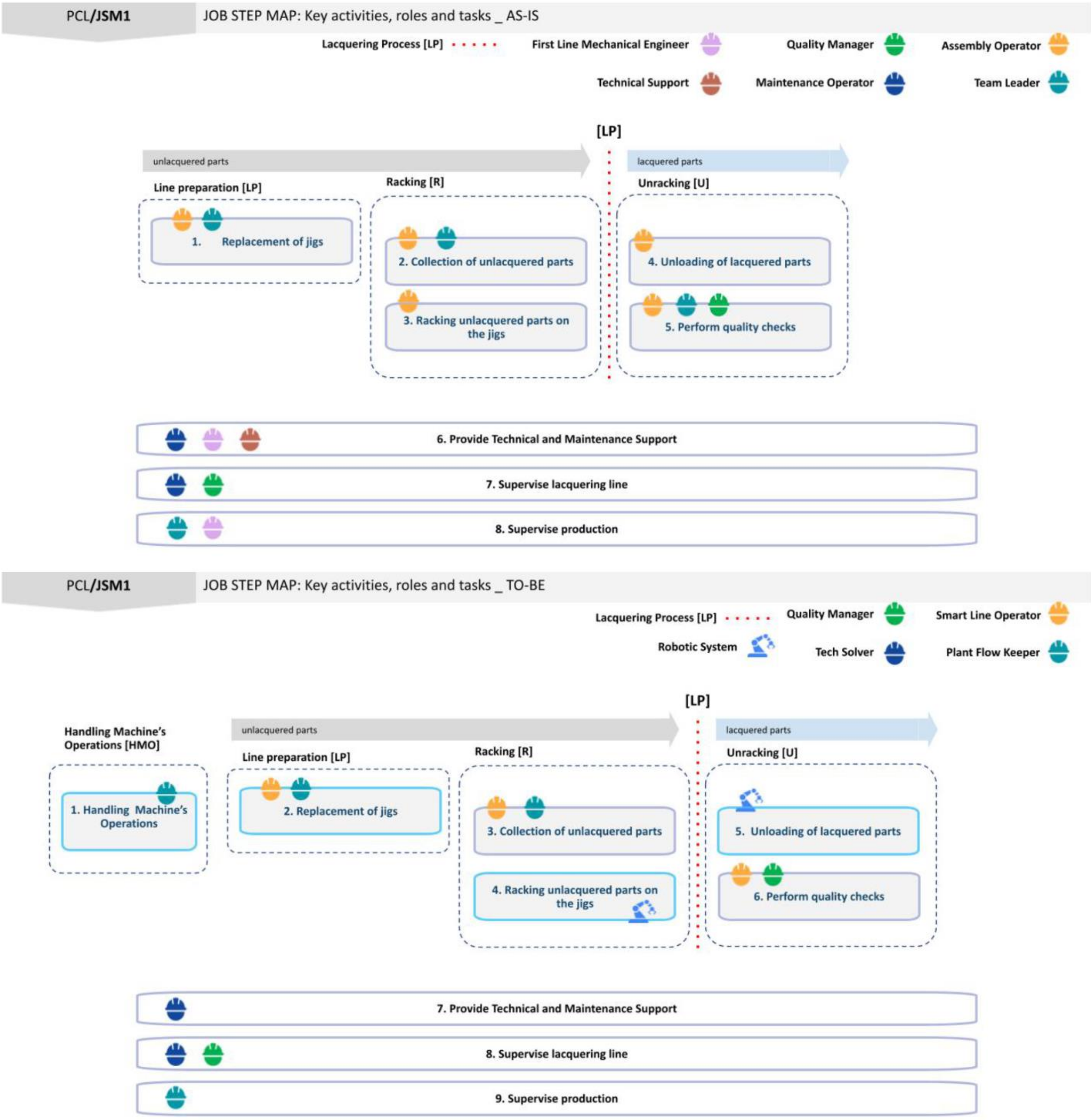

Figure 13. Job Step Map transformation of the as-is (above) and to-be (below) scenarios in the PCL use case

3.4.3. TOFAS

In the first TOFAS use case, the three operators of the AS-IS scenario assumed the new roles of Smart Line Operator and Plant Flow-Keeper (Figure 14). As a new team mate, the Robotic System is included to perform the outbound boxes preparation together with the Smart Line Operator, as in Figure 15.

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In the second TOFAS use case, the Operator, Team Leader and Maintenance operator, in the TO-BE scenario are represented with the Smart Line Operator, the Plant Flow-Keeper and the Tech Solver (Figure 16). While the Quality Leader remains as a separate specialised role called Quality Manager. Also in this case, a robotic system is included in the operational team, specifically for the kitting and assembly tasks, as shown in Figure 17.

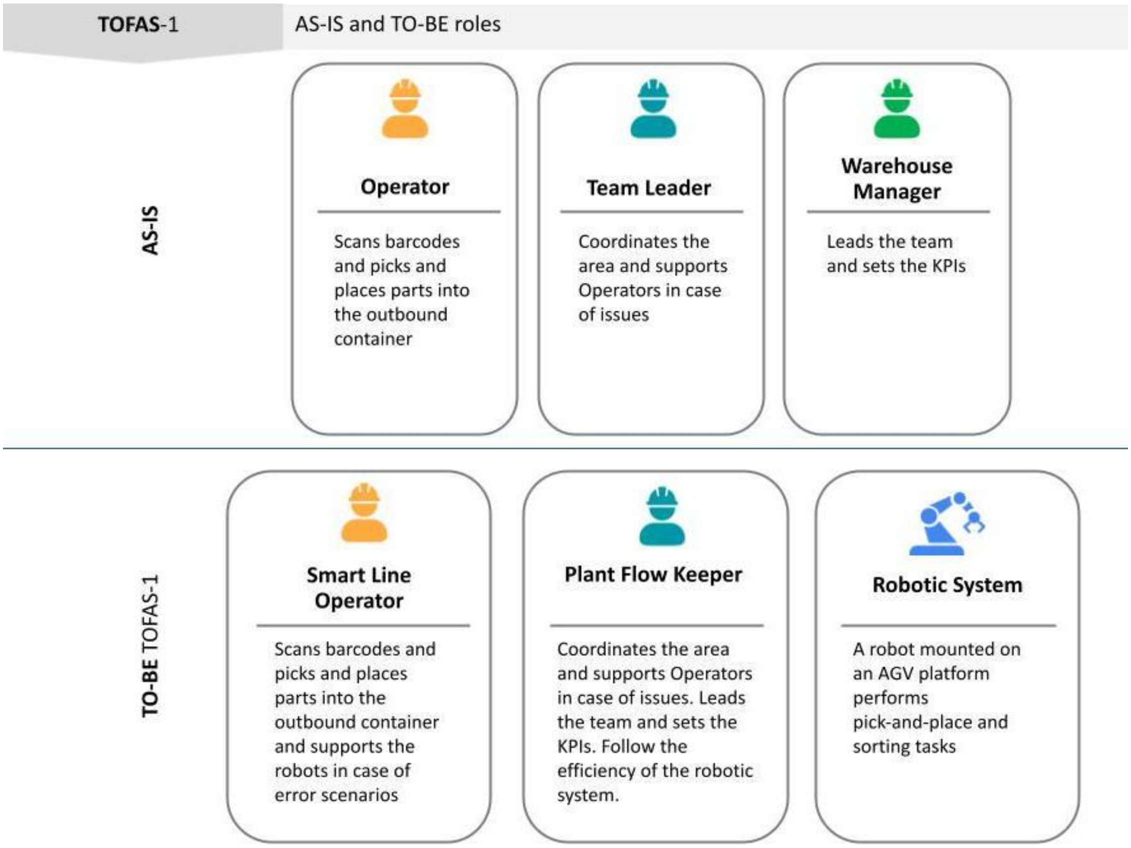

Figure 14. Roles transformation in the first TOFAS use case

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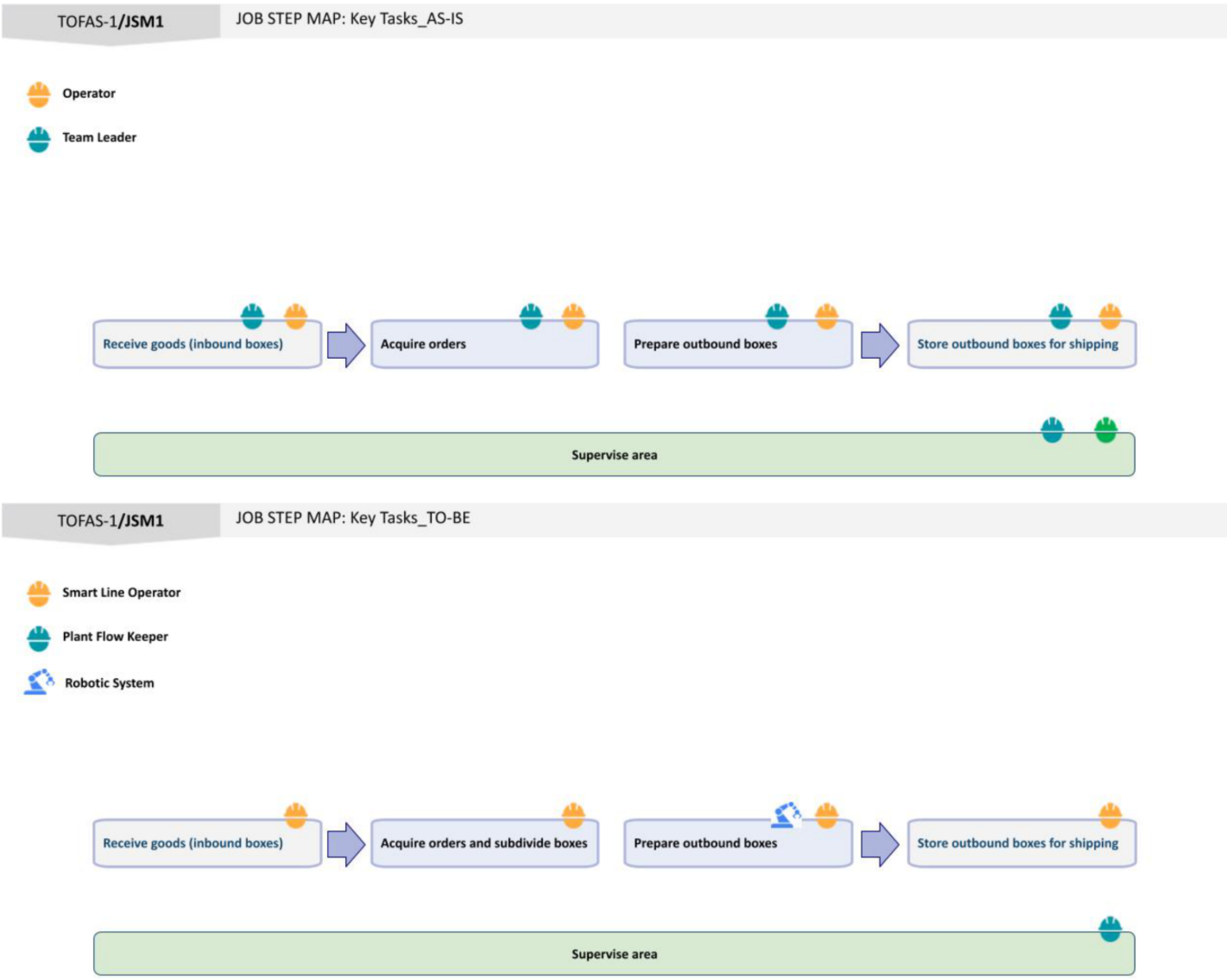

Figure 15. Job Step Map transformation of the as-is (above) and to-be (below) scenarios in the first TOFAS use case

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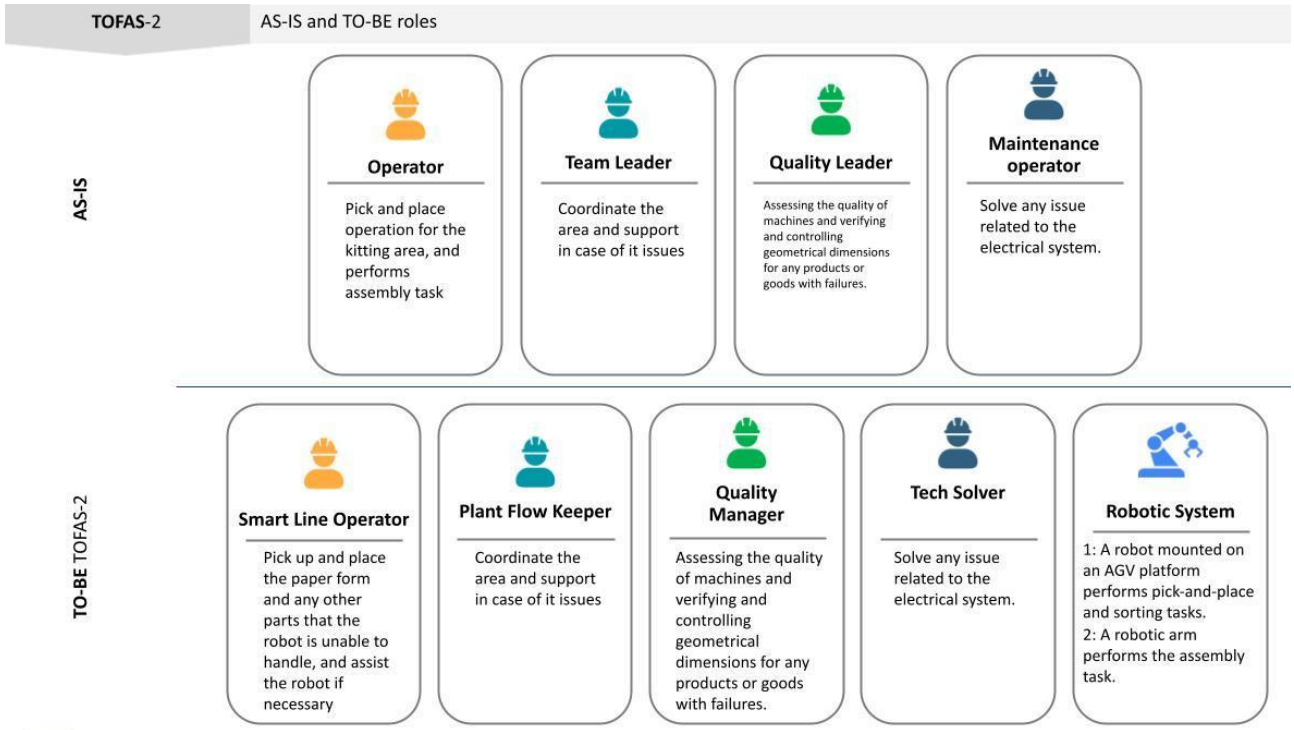

Figure 16. Roles transformation in the second TOFAS use case

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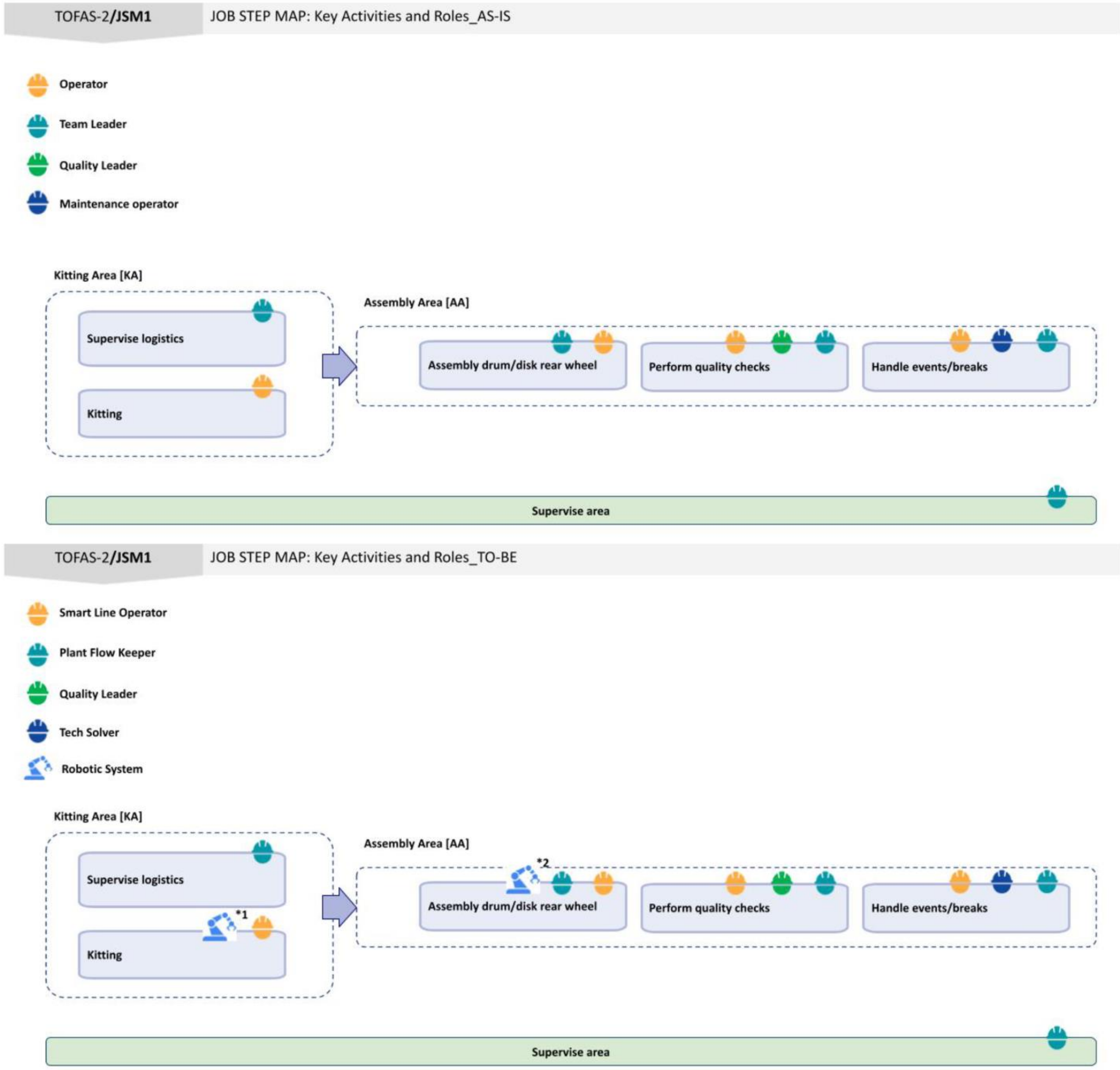

Figure 17. Job Step Map transformation of the as-is (above) and to-be (below) scenarios in the second TOFAS first use case

3.4.4. ULMA

In the ULMA use case, in the TO-BE scenario the three human operators assumed the new roles of Smart Line Operator and Plant Flow-Keeper and Tech Solver (Figure 18), together with a Robotic System as a new team mate for the order preparation phase (Figure 19).

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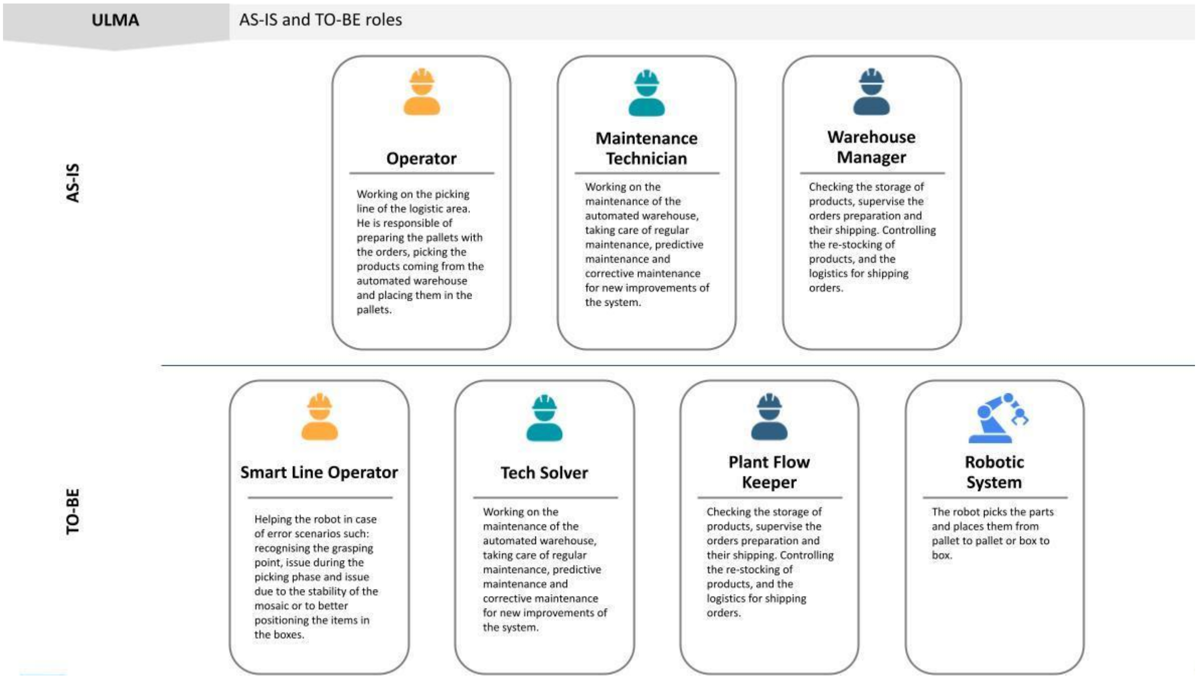

Figure 18. Roles transformation in the ULMA use case

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Figure 19. Job Step Map transformation of the as-is (above) and to-be (below) scenarios in the ULMA use case

3.4.5. INFAR

In the INFAR use case, the two operators are now represented by the Smart Line Operator profile (Figure 20) that works alongside with a Robotic System (Figure 21).

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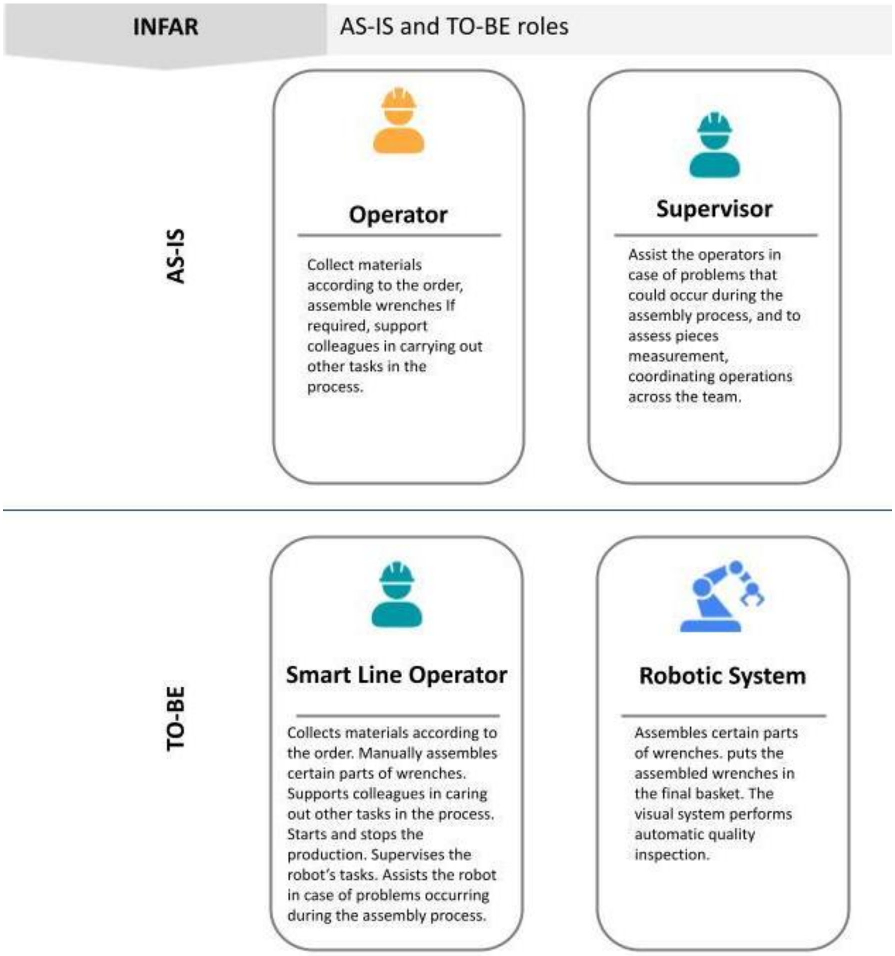

Figure 20. Roles transformation in the INFAR use case

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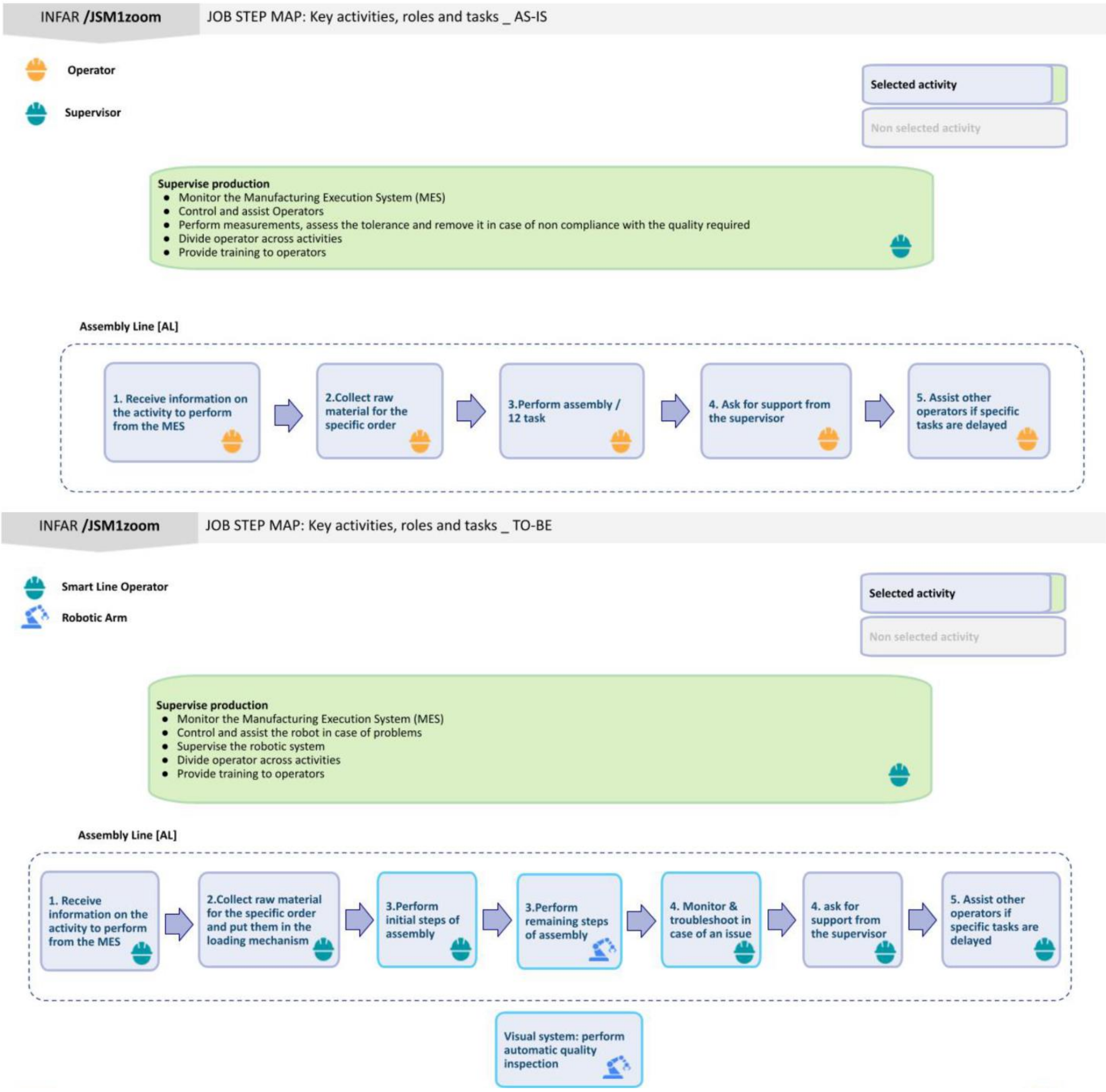

Figure 21. Job Step Map transformation of the as-is (above) and to-be (below) scenarios in the INFAR use case

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4. Human-Centric Design and Training Guidance

The Human-Centric Design and Training Guidance is a set of actionable design and training recommendations developed through a structured, multi-layered analysis grounded in:

- on field observations of the five operational use cases;
- detailed examination of the corresponding RACI matrices (see D1.6 Section);
- expert analysis in human factors, human–robot interaction, and manufacturing operations;
- on-site testing of HARTU's solution in one use case;
- iterative interpretation of workflow breakdowns, escalation dynamics, and interaction patterns carried out with technological stakeholders and use-cases.

The guidelines translate real operational challenges into structured, context-sensitive design and training measures aligned with established human-centred design principles.
Across all scenarios—both regular and IF Scenarios—clear patterns emerged in how Smart Line Operators, Plant Flow-Keepers, and Tech Solvers interacted with HARTU's solution. These patterns revealed specific needs related to responsibility clarity, workflow consistency, communication, and skill development, which guided the creation of the guidelines. The guidelines are organised into four interconnected sections that address the key human factors influencing trust, acceptance, and effective interaction with the new technological system.

The goal of the Human-Centric Design and Training Guidance is to support safe, efficient, and trustworthy integration of automated Industry 5.0 systems in manufacturing environments by offering practical recommendations for the design team of innovative technological solutions (e.g., tech developer, human factors experts, HR, factory management).

The structure reflects both established human-centred design principles and insights derived from the analysis of the operational use cases and testing, that were transformed into guidelines.
The Guidelines are organised into the following five sections:

1. Procedures, workspace and working practices

This section addresses the elements that directly shape how operators perform actions in the physical environment. It includes procedural clarity, workspace cues, and the design of step-by-step instructions that guide proper execution. The focus is on ensuring that the procedures and the physical layout support intuitive, consistent, and error-resistant interaction with the technology. This section focuses on defining clear roles, responsibilities, and workflows for humans, robots, and AI systems. It includes guidance on role allocation, authority boundaries, escalation paths, and the design of procedures that support safe and efficient collaboration. Training recommendations mirror these aspects by teaching operators how to interpret system signals, perform supervisory actions, and intervene correctly during automated workflows.

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Focuses on:

- how operators physically interact with the environment
- how procedures guide mechanical or sequential tasks
- how workspace cues affect performance

Roles are *referenced* but not treated in depth here.

2. Human Performance Transition Factors

This section examines the cognitive, perceptual, and workload-related factors that influence how operators adapt to the new system. It covers aspects such as the clarity of visual information, workload balancing, error signalling, and the system's alignment with human perceptual limitations. These factors are essential to ensure safe operation and smooth transition during early adoption. It includes design guidance on reducing cognitive overload, pacing transitions, and providing structured support for error management. Training guidance focuses on building operators' capacity to manage alerts, troubleshooting, multitasking, and handling irregular events confidently.

Focuses on:

- cognitive load
- perceptual ergonomics
- adaptation to new workflows
- workload management

3. Teams & Communication

This section outlines how to ensure clear, consistent communication and shared situational awareness among humans and automated systems. It includes design requirements for feedback signals, shared displays, coordinated escalation procedures, and safety cues. The training guidance prepares teams to communicate effectively during normal and non-nominal events, maintain awareness across roles, and collaborate smoothly with both human colleagues and AI/robot components. It reflects the organisational dynamics observed in the RACI matrices analyses and use cases (see D1.6), emphasising escalation pathways, consistent information sharing, and teamwork between operators, supervisors, and support roles.

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Focuses on:

- coordination between roles
- escalation pathways
- shared situational awareness
- cross-role communication consistency

4. Skills, Roles and Responsibilities

This section covers the knowledge and competencies operators need to interact effectively with the system. It includes technical skills, interface literacy, error-handling capabilities, and opportunities for practice-based learning. It also addresses role clarity and responsibility definition, since understanding who does what, when intervention is permitted, and how escalation should occur is fundamentally a matter of operator competence and readiness. Based on the use cases, operators' recurring questions—such as *"Can I intervene?", "Whom should I notify?",* and *"Is this my task?"*—show that role comprehension is a critical training requirement rather than merely a procedural one. The associated training guidance ensures that operators maintain essential manual competencies and develop expertise appropriate to their experience level, from novice to advanced.

Focuses on:

- role clarity and responsibility definition
- practical skill building and training
- system literacy (alerts, resets, feedback interpretation)

5. Ethics and Liability

This section focuses on ensuring transparency, accountability, human control, and compliance in human–AI–robot collaboration. It includes design recommendations for explainability, traceability, safe overrides, participatory practices, and data protection. The training recommendations teach operators when and how to intervene, how to document decisions, and how to recognise ethical or safety-relevant concerns, supporting responsible and compliant system use.

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Focuses on:

- transparency in human–AI–robot collaboration
- accountability in operations and decision-making
- human control over critical actions
- compliance with ethical, organizational, and regulatory standards

As an example, the RACI analysis showed that Smart Line Operators carry the majority of hands-on responsibilities across all workflows, particularly in non-nominal situations such as fallen parts, mosaic collapses, misdetections, and obstacle handling. Their central role in monitoring the system, interpreting alerts, and restoring nominal operation highlighted the need for clear procedures, supportive workspace cues, and interfaces that reduce ambiguity during execution. These findings directly informed guidance in **Section 1 (Procedures & Workspace Design)**, which focus on ensuring that procedural steps, physical layouts, and workspace signals collectively support intuitive, consistent, and error-resistant operator actions.

Many operational tasks also required high precision, such as crate alignment, jig positioning, and item placement. However, field observations revealed frequent misalignments between system feedback and what operators could physically see, leading to confusion and slower troubleshooting. These insights formed the basis of **Section 2 (Human Performance Transition Factors)**, which emphasises perceptual ergonomics, step-by-step procedural guidance, workload management, and error visibility rules that match the operator's physical perspective rather than solely the vision system's detection logic.

The workflows examined also showed a multilayered team structure, especially in non-nominal events. Coordination between Smart Line Operators and Plant Flow-Keepers was essential whenever system recovery failed, obstacles could not be removed, or abnormal conditions persisted. There, the involvement of the Chief Plant Flow-Keeper and the Tech Solver occurred primarily during escalated or technically complex events. These dynamics shaped **Section 3 (Teams & Communication)**, highlighting the need for reliable communication channels, consistent shared-awareness cues, structured escalation pathways, and cross-role training to ensure that all actors intervene coherently and confidently.

Field testing further revealed strong variation in operators' ability to interpret interface cues, light indicators, and troubleshooting steps. Differences in experience, language proficiency, and familiarity with automation significantly affected the speed and accuracy of interventions. These observations guided **Section 4 (Skills & Training)**, which focuses on designing training programmes that build practical competence, clarify roles and responsibilities, support multilingual or simplified communication needs, and strengthen operators' understanding of system behaviour. Particular

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emphasis is placed on scenario-based learning and interface literacy, ensuring that users can act effectively and safely within the new human–machine workflow.

Finally, concerns related to liability, transparency, and fairness emerged indirectly through interviews and ambiguity in system states. Operators were sometimes unsure whether manual intervention was permitted, whether a reset action would be recorded appropriately, or how responsibility was assigned when system feedback did not match the robot's physical behaviour. These insights shaped **Section 5 (Ethics & Liability)**, which addresses the importance of transparent system communication, traceability of actions, and clear boundaries of responsibility so that operators feel supported and protected when interacting with the technology.

Together, these observations created the foundation for the unified guidance framework. The recommendations do more than reflect generic best practices—they directly respond to issues observed in real workflows, ensuring that the proposed design and training measures are practical, context-specific, and supportive of safe, efficient, and trustworthy technology adoption across all operational roles.

The Human-Centric Design and Training Guidance are intended to support both the development of the technological solution and the preparation of the personnel who will operate it.

The Guidance is divided into a structured set of **Design Guidelines (D)** and **Training Guidelines (T)** across the five sections presented above: (1) Procedures, workspace and working practices; (2) Human performance transition factors; (3) Teams and communication; (4) Skills, roles and responsibilities; and (5) Ethics and liability. The consideration of both the Design and Training guidelines ensures that operational procedures and training programmes support safe, effective, and transparent human–AI–robot collaboration. The **Design Guidelines** (listed in Table 2) should be applied throughout the entire development lifecycle—*before*, *during*, and *after* the design phase. In the early stages, they inform system requirements, shape initial concepts, and ensure that human needs and operational constraints are embedded from the outset. During development, they guide decisions related to interface design, workflow integration, and workspace layout, ensuring that usability and operator experience are treated as core design criteria. After the system has been developed, these guidelines also serve as a basis for validating prototypes, conducting usability assessments, and refining the final implementation to ensure alignment with real operational contexts. In parallel, the **Training Guidelines** (listed in Table 3)are meant to be applied *before* deployment and *during* the onboarding phase of the personnel. They support the creation of training materials, the definition of curricula, and the preparation of operators for real working conditions. Following deployment, they provide a foundation for refresher training, competence updates, and continuous improvement activities as the system evolves. Together, these two families of guidelines ensure both a human-centred technological design process and a structured, effective preparation of all operational roles involved in the adoption of the new system.

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Table 2. Design Guidelines

Design Guidelines	
1. Procedures, workspace and working practices	
D1.1 – Define clear and well distinct roles for each actor (human and non-human) involved in a working scenario. Clearly define responsibilities for all human and automated actors. Clear role allocation enhances coordination, accountability, and situational awareness, reducing ambiguity and operational errors	
	D1.1.1 – Define Human–AI/Robot Roles and Relationships Based on the Type of Activity Example: Categorise key workflow activities (e.g., Planning, Task Execution, Quality Control, Alarm Management, Monitoring, Troubleshooting, and Corrective Actions). For each type of action, assign roles to the human operator (e.g., Collaborator, Supervisor, Assistant, etc.) and in relation to the the AI/Robot (e.g., human supervisor, robot executor, AI recommender), along with the level of autonomy granted to the AI system.
	D1.1.2 – Maximise complementarity of roles, treating all team components (e.g., human, robot, AI) as distinct agents with specific tasks, contributing to the procedure with different autonomy levels. Example: Each component in the workflow — whether human, robot, or AI — is defined as an individual contributor with clear responsibilities. The allocation of tasks is designed so that human strengths (e.g., judgment, flexibility) and AI/robot strengths (e.g., precision, speed, repeatability) complement each other, avoiding overlaps and gaps in responsibility. For instance, the AI may handle rapid measurements or calculations, the robot executes precise repetitive movements, and the human operator makes judgment-based decisions on quality deviations. if this is the case, allocate judgment-based tasks (e.g., quality decisions) to humans, while robots handle repetitive precision tasks and AI assists with rapid measurements or classification.
	D1.1.3 – Clearly define when control belongs to the system/robot/AI and when responsibility returns to the human operator. Example: A robot may execute inspection steps autonomously, but humans always validate results before the workflow continues, with clear escalation rules for exceptions. Clearly specify the exact moments where control and responsibility shifts from human to AI/Robot and vice versa. Include escalation rules for exceptions or unexpected events.
D1.2 – Integrate role updates and monitoring responsibilities into official procedures. Regularly revise duties in the Management System or internal documentation. Update internal documentation and the Management System whenever role changes occur, and ensure all operators have access to the latest procedures. This can improve consistency and reduce operational errors.	
	D1.2.1 – Provide simple, accessible reference tools (e.g., printed flowcharts). Example – Place printed flowcharts or laminated guides showing key responsibilities at operator stations, so staff can quickly check who is responsible for alerts, interventions, or escalations.

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D1.3 – Ensure Human Involvement at Critical Process Stages Actively involve human operators in tasks that require decision-making, oversight, or troubleshooting. Reduce purely passive monitoring roles. Design workflows that explicitly incorporate human actions at critical points, supporting higher engagement and improved situational awareness. Ensure that human responsibilities remain meaningful, so that human contribution enhances overall system reliability and mitigates risks associated with over-automation.	
	D1.3.1 - Ensure that robot monitoring and supervision are not a passive Example - Supervisory tasks are combined with compatible activities that maintain situational awareness. For example, while a robot is performing sorting, the operator simultaneously prepares replacement components or reviews system logs in a nearby area, maintaining oversight and enabling rapid intervention if errors occur. While observing a robotic arm, the operator might organize materials for upcoming steps, check calibration status or data logs, work on a closeby line manually, or track previous alerts, ensuring that human engagement remains active throughout the process.
D1.4 – Preserve operator authority in safety and compliance-relevant decisions. Ensure that human operators retain final authority over decisions with safety or compliance implications, even when automated systems provide recommendations or detect correct conditions. Require human review and confirmation before the workflow proceeds in critical steps, maintaining accountability and preventing over-reliance on automation. Preserve operator trust and risk reduction by keeping humans in control of decisions that carry significant operational consequences.	
	D1.4.1 – Define explicit procedural boundaries between autonomously initiated and human-confirmed actions Example: Semi-automated sequences should automatically pause at critical assembly or inspection steps to allow Operators to verify alignment, placement, or other safety/reliability criteria before resuming. For example, in a semi-automated assembly station, the robot positions a component, but the workflow pauses until the operator confirms the alignment using visual indicators or sensors before continuing. Procedures must specify when the human should verify, approve, or act on system outputs.
2. Human Performance Transition Factors	
D2.1 – Ensure operators can complete all tasks safely, independently, and consistently, without relying on informal or ad-hoc guidance from supervisors. Ensure operators can complete tasks independently, safely, and consistently, without relying on ad-hoc guidance from supervisors. Support may include step-by-step instructions, visual aids, or procedural checklists.	
	D2.1.1 - Provide step-by-step instructions for setup and maintenance activities. Example – Operators are guided through procedures using checklists, sequential instructions, and visual cues. For example, instructions for equipment setup, calibration, routine cleaning, or component replacement are clearly displayed at the workstation, allowing operators to complete each step correctly and safely.

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	D2.1.2 - Develop detailed procedures for error and failure management Example - Operators follow clear fault-handling procedures, including flowcharts, escalation paths, and safety checks. For example, if a sensor fails to detect an item, the operator follows a defined sequence: perform a manual reset, notify the Plant Flow-Keeper if the issue persists, and escalate to a Tech Solver in case of suspected damage.
	D2.1.3 - Clarify how, when, and why operators must intervene during monitoring tasks Example - Operational roles know exactly when intervention is required and what thresholds trigger it. For example, monitoring tasks include defined alert levels: a minor misalignment triggers a prompt to verify placement, while a system fault requires immediate manual correction and notification of supervisors.
D2.2 - Apply cognitive ergonomics principles to multitasking and task prioritization Design workflows, interfaces, and alerts to reduce cognitive load, helping operators prioritize effectively when handling multiple monitoring or intervention tasks. Ensure that the system is designed to reduce unnecessary mental switching between tasks, preventing cognitive overload especially during complex operations.	
	D2.2.1 - Balance operator workload with supportive interactive prompts. Example- When supervising several parallel processes, operators receive clear prompts that highlight deviations or anomalies, helping maintain situational awareness across tasks and ensuring anomalies are noticed promptly.
	D2.2.2 – Design workflows that minimise abrupt cognitive shifts when transitioning between automated and manual actions. Example: A semi-automated station provides early notifications such as “manual alignment required next,” preventing abrupt shifts in attention when the system pauses.
	D2.2.3 – Pace task transitions so the operator is not overloaded when moving from supervisory to corrective work. Example: Systems provide pauses for review and confirmation before continuing.After a robot completes a movement requiring human validation, the workflow automatically pauses. The operator reviews status, confirms the next action, and only then the system resumes, reducing the risk of error and cognitive overload.
3. Teams & Communication	
D3.1 Ensure clear guidance and feedback of human operations Provide operators with precise and actionable information that supports both manual task execution and situational awareness in collaborative workflows. Clear and well-timed guidance improves coordination, reduces errors, and enhances team performance.	

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	D3.1.1 - Provide clear guidance (e.g., visual cues) to indicate where and how the operator should perform manual tasks in collaboration with the robot. Example - A blue light projection outlines the exact position and orientation where the operator should place a component for the robot to pick up.
	D3.1.2 - Implement real-time feedback mechanisms at the point of action. Example - A green light displayed on the placement surface confirms that the object has been positioned correctly.
	D3.1.3 - Include contingency steps for unplanned events in procedures. Example – Define clear escalation paths and “what to do if…” guidance, developed collaboratively with the team before issues occur. If a suction cup does not reset after manual realignment, the operator follows a defined path: attempt manual reset → notify the Plant Flow-Keeper → escalate to Tech Solver if damage is suspected. Preparing these steps in advance helps prevent safety issues and improves cross-role coordination.
	D3.1.4 – Provide shared information displays that help humans and AI maintain a common understanding of workflow progress. Example: A planning interface shows AI recommendations, pending operator approvals, and next expected actions, keeping humans and AI aligned on workflow status.
D3.2 - Provide mechanisms that convey safety and reassurance during human–robot interaction Implement design features that clearly communicate system safety, operational limits, and robot status. These mechanisms help operators feel confident when entering or working near robotic areas.	
	D3.2.1 - Ensure all components are inactive when the robot stops Example - When the robot stops, the vacuum gripper is fully deactivated (i.e., no suction occurs) the arm is locked in place, and safety sensors prevent unintended motion. This guarantees that all connected modules remain inactive so operators can approach and manipulate objects safely.
	D3.2.1 - Provide feedback to indicate a safe working area Example - When it is safe to enter the robot’s working area, the perimeter lights around the robot glow green signaling it is “Safe to Enter” . An auditory confirmation signals that the area is secure. This way Operators can immediately identify safe conditions, reducing hesitation or uncertainty.
D3.3 - Ensure clear understanding of warning or error messages Provide operators with understandable, timely, and context-aware warning and error messages. This supports correct interpretation, reduces false interventions, and improves troubleshooting efficiency.	

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	D3.3.1 - Synchronise warning with machine status. Example - Ensure messages are synchronized with visible or perceivable machine conditions and clarify sensor-based detections. Display an error message only when the issue is visible or perceivable (e.g., robot stops, item falls, obstacle detected). If a sensor detects an issue earlier than when it appears visible to the human, add clarification such as: "Detected by vision system, not yet visible." This supports operators' efficiency and response.
	D3.3.2 - Display visible problem notifications where the operator's intervention is required. Example - If the robot fails to recognize an object, highlight the unrecognized area within the robot's field of view. A visual indicator appears on the workbench surface showing where the operator should act. Operators can immediately locate the problem area, reducing search time and errors.
D3.4 - Ensure proper communication and transparent status information during troubleshooting processes. Maintain transparent information about workflow status, pending validations, and operator-required steps. Clear communication supports situational awareness and prevents coordination gaps.	
	D3.4.1 - Provide verification for problem resolution Example - Require a manual or automatic verification step before reactivating the system after troubleshooting. A "Verify problem resolution" button appears next to the error message, allowing operators to confirm the fix before restarting, ensuring safety and accountability.
	D3.4.2 - Clearly indicate robot step completion and next operator action Example – Use visual confirmation markers and highlighted instructions for the next required step to prevent coordination gaps. After the robot completes an assembly step a green checkmark appears on the interface next to the completed task, and an highlighted panel instructs the operator on the next manual adjustment or verification step.
	D3.4.3 – Support situational awareness with transparent workflow state, robot/AI status, and next required steps Example – Provide continuous visibility into robot/AI status, pending validations, and required actions. The operator always sees the robot's current task, pending validation steps, and upcoming manual actions. Progress bars indicate workflow completion, and deviations are highlighted immediately. This ensures the operator and AI/robot remain aligned, reducing coordination gaps and improving safety, maintaining awareness during sequential coordination.
4. Skills, roles and responsibilities	
D4.1 – Support skill development through well-designed features Include visual cues and intuitive interface elements that facilitate skill acquisition and procedural learning. Design features can guide correct actions, improve memory retention, and accelerate operator competency development.	

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	D4.1.1 – Use instructional cues that guide operators *during* task execution. Example – Provide visual, spacial or interface-based cues that support operators in performing checks, assessing hardware conditions, and ensuring correct placement. Use colour-coded markings to highlight the correct positioning area, show enlarged on-screen examples of “correct” vs. “incorrect” grips, or provide simplified diagrams to support troubleshooting. Group interface buttons by task type, use clear confirmation messages, and design intuitive interaction flows to reduce cognitive load and shorten learning curves.These cues function as real-time guidance tools, strengthening procedural memory and helping novice operators reach proficiency fastly.
D4.2 – Ensure the system supports users with varying levels of experience. Provide guidance features that accommodate both novice and experienced operators, ensuring safe and effective performance across different experience levels.	
	D4.2.1 – Provide system feedback that supports the development of diagnostic and troubleshooting skills. Example: When alerts occur, the system should offer clear, descriptive information that helps operators learn to diagnose issues. If an AGV triggers a sensor alert, display explicit messages such as “localisation issue” or “obstacle detected” to support effective problem identification.
D4.3 – Incorporate clear feedback on performance and error recovery. Provide consistent feedback and indicators on task performance and error recovery. Feedback can support learning, improve confidence, and reinforce correct procedures.	
	D4.3.1 – Provide clear *post-action* feedback that confirms successful task execution or guides corrective action. Example - After an operator completes a manual correction (e.g., realigning a part or resetting a sensor), the should deliver explicit feedback such as a green signal, a “Correction Successful” message, or an updated status bar. If the issue remains unresolved, the interface highlights the persisting error and offers targeted prompts (e.g., “Alignment still off – recheck left edge”). This feedback helps operators understand the effectiveness of their actions, reinforces correct procedures , and prevents workflow continuation if the recovery is incomplete.
D4.4 – Preserve essential manual and procedural skills by ensuring the system requires meaningful operator actions in critical steps. Maintain operator engagement in tasks requiring judgment, alignment, or quality checks, preventing over-reliance on automation and strengthening supervisory skills.	
	D4.4.1 – Design interactions that strengthen human supervisory skills rather than replacing them. Example: In a problem-solving/decision-making process, a worker reviews an AI proposal in a dashboard that displays supporting data, quality KPIs, and contextual indicators, helping them decide whether to accept, modify, or reject the suggestion.
5. Ethics and Liability	
D5.1 – Ensure transparency of system behaviour and limitations. Make system capabilities, limitations, and uncertainties visible and understandable to operators. Transparency enhances trust, informed decision-making, and appropriate reliance on automation.	

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	D5.1.1 - Design the system with transparency and explainability requirements. Ensure the AI is traceable and explainable at every stage of the process. Example - When vision recognition is uncertain, the interface displays confidence levels (e.g., “90% confidence”, “20% confidence”) to help the operator assess reliability. This level of transparency and explainability ensures personnel understand both system capabilities and limitations.
	D5.1.2 – Ensure traceability of decisions and automated actions. Example – The system records all decision steps and triggered actions in a Log/database, enabling post-event analysis and verification.
D5.2 – Maintain meaningful human control over automation. Preserve human authority over critical operations and decisions. Provide override mechanisms and manual controls to ensure accountability and safety.	
	D5.2.1 - Preserve human control at the start and end of every process. Example – Provide safe override options, manual stop buttons, and accessible supervision tools that maintain operator agency throughout the workflow.
D5.3 - Mitigate risks and promote acceptance of new systems through participatory and transparent practices. Implement co-design, continuous evaluation, and reporting mechanisms for unsafe, unfair, or ethically problematic behaviours to strengthen safety, usability, and user trust.	
	D5.3.1 – Integrate reporting mechanisms for unsafe, unfair, or ethically problematic system behaviours. Example - Include a “Report Issue” button to flag concerning system actions about incorrect or biased behaviour in semi-automated sequences."
D5.4 – Ensure compliance with ethical, organisational, and regulatory standards. Ensure AI and robotic system suggestions comply with sector regulations, labour protocols, and ethical principles; protect operator autonomy in decisions involving legal or ethical implications.	
	D5.4.1 – Protect user data, operator rights, and workplace well-being through responsible information handling. Handle information responsibly by storing only performance-related system logs and avoiding inappropriate monitoring or exposure of personal data. System logs focus on task and performance data, without collecting identifiable personal information.

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	D5.4.2 – Include safeguards that ensure operators retain autonomy in decisions with ethical or liability implications. Example: Ensure operators retain final confirmation authority in decisions with ethical, safety, or liability implications. Even if the robot detects a correct condition, the workflow requires human approval before certification, preserving accountability.

Table 3. Training Guidelines

Training guidelines	
1. Procedures, workspace and working practices	
T1.1 – Provide role-based training that clarifies the boundaries of responsibility. Design training programmes that clearly define operators' responsibilities,including alert supervision, operational interventions, and escalation steps.This supports safe and effective collaboration with AI and robotic systems.	
	T1.1.1 – Reinforce responsibility through peer-shadowing and on-the-job mentoring Example – Organise peer-shadowing and on-the-job mentoring sessions where Line operators observe and practise responses to events such as mosaic collapse, misclassification, or missing items in trays. This hands-on exposure builds confidence in low-frequency scenarios and provides supervisors with insights for adjusting intervention flows.
	T1.1.2– Provide structured demonstration and observation-based learning Example –Include live demonstrations and guided observation sessions during onboarding to strengthen correct task execution. Operators practise identification of issues, interpreting system feedback, and performing precise manual interventions through real or simulated scenarios, reducing reliance on expert support.
T1.2 – Ensure users know how to interpret quick-reference tools during work. Train operators on when and how to consult quick-reference guides, checklists, or instructional videos during non-standard events or troubleshooting. This ensures the correct use of support tools during unexpected alarms or rare errors.	
T1.3 – Provide task-based training that clarifies responsibility boundaries. Develop exercises focusing on specific operational tasks, highlighting who is responsible for each decision or action. This promotes accountability and reduces ambiguity in human–automation workflows.	
	T1.3.1 – Clarify how operators should intervene during monitoring tasks. Example –Use case-based training to show when manual action is appropriate or required. Develop and role-play scenarios to illustrate exactly when operators may intervene or when they must escalate.

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	T1.3.2 – Train operators to recognise the exact moments when they must take back responsibility from the AI. Example: Use live or simulated workflows that highlight system signals indicating critical steps requiring human verification. Operators learn to identify cues such as robot step completion prompts that require manual confirmation.
	T1.3.3 – Train operators to exercise judgement in cases where AI recommendations must be validated for compliance or safety. Example: Provide exercises that require operators to double-check Robot/AI-detected conditions for compliance and safety.
	T1.3.4 – Train operators to perform supervisory evaluations of AI outputs. Example: Create structured exercises and role-play scenarios enabling operators to review AI suggestions critically.Operators compare AI suggestions with operational constraints and practise applying justified overrides to maintain safety and efficiency.
2. Human Performance Transition Factors	
T2.1 – Train operators to manage cognitive switching between monitoring and active intervention. Develop training that strengthens operators' ability to alternate between monitoring AI/Robot outputs and performing manual validations or corrections. This supports attentional flexibility in mixed-initiative workflows.	
	T2.1.1 – Train operators to handle variable task pacing caused by system-triggered pauses or human confirmation steps. Example: Include exercises that prepare operators to manage system-triggered pauses, manual confirmation. Operators practise alternating between automated actions and manual validation steps during inspections or workflows that require periodic human intervention.
T2.2 - Consider the increase of operator competencies needed for Problem/Alert Management, technical issue resolution, and robot controller usage Provide hands-on training to practise alert response, technical troubleshooting, and safe operation of robot controllers. Prepare operators for both routine and exceptional situations.	
T2.3 -Use case-based training to simulate scenarios requiring manual action Design case-based exercises where operators practise machine setup, routine maintenance, alarm response, and rare-event management. This builds confidence in non-nominal situations and strengthens readiness for unexpected events.	

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T2.4 - Implement structured repetition in early training stages Use step-by-step walk-throughs and guided practice for setup, troubleshooting, and alarm management tasks until operators can perform confidently without assistance. Structured repetition reinforces procedural memory and supports consistent performance.	
T2.5 - Educate users on how to manage multitasking using the prompts. Train operators on how to manage simultaneous monitoring and intervention tasks by correctly interpreting system prompts. Emphasize alert prioritization, task sequencing, and the use of prompts.	
3. Teams & Communication	
T3.1 – Train teams on shared situational awareness practices and communication expectations Develop training on standard communication phrases and procedures to maintain shared awareness during workflow handovers or interruptions.	
	T3.1.1 – Train operators to re-establish situational awareness after system's interruptions or task handovers. Example - Include exercises where operators assess workstation status after automated pauses or shift handovers, check pending alerts, and confirm next steps before resuming work. For example, after an automated pause, an operator reviews the workstation status, checks pending alerts or corrections, and confirms the next step before resuming the sequence. This ensures smooth continuation and prevents errors caused by loss of context.
	T3.1.2 – Train operators to mantain shared situational awareness with both the AI system and team members. Example - Practice cross-checking AI suggestions with manual observations and communicating decisions to the team, ensuring alignment and minimizing miscoordination.For example, after reviewing AI-suggested actions, an operator confirms the plan with colleagues and updates the AI system accordingly, keeping all actors aligned and informed.
T3.2 – Train users on collaboration workflows and communication expectations specific to non-nominal scenarios. Include structured exercises where operators follow escalation protocols, coordinate manual and automated actions, and communicate clearly with supervisors, Tech Solvers, and peers.	
	T3.2.1 – Train operators in structured escalation protocols and communication during abnormal events. Example- Provide scenarios where teams practise determining responsibility for manual corrections and restarts, using standardized templates for reporting deviations, faults, or corrective actions. For example, when an automated station pauses, the team practices determining who performs the manual corrective action and who restarts the workflow, maintaining smooth collaboration. Operators practise on when to notify supervisors, Tech Solvers, or peers, depending on the severity or type of event. While doing so, operators practise reporting deviations or faults using a standardized template specifying the type of alert,

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	probable cause, and corrective action taken. This ensures clarity, consistency, and faster resolution during unexpected situations.
	T3.2.2 – Train operators to integrate AI-related communication into human team coordination. Example - Use exercises where teams rehearse coordinating manual interventions and restarts, applying standard phrases (such as “Robot stopped for safety,” “Obstacle removed,” or “Manual step required next.”) to ensure consistency and maintain awareness across roles. Teams rehearse managing interruptions when automated systems pause, coordinating who performs manual corrective actions and who restarts the sequence. This training builds smooth collaboration and prevents coordination gaps.
T3.3 – Provide joint training sessions for all roles involved. Design scenario-based exercises that include multiple roles (operators, supervisors, Tech Solvers, etc.) to experience end-to-end workflows, including collaborative troubleshooting, escalation, and decision-making under realistic conditions.	
	T3.3.1 – Train teams through scenario-based exercises. Example – Scenario-based exercises simulate deviations such as fallen items or misdetections, allowing operators to practice their role while coordinating actions as a team. This improves multi-role decision-making, communication, and overall collaboration under realistic conditions. For example, adter a fallen item or misdetections Smart Line Operators, Plant Flow-Keepers, Supervisors, and Tech Solvers practise multi-role responses to realistic deviations. These exercises develop coordination, decision-making, and communication skills under conditions that closely mirror real operations.
T3.4 – Train users on the meaning of visual markers and how to use them. Educate operators on floor/workstation markings, system alerts, interface layouts, and feedback signals to ensure correct responses and timely interventions.	
	T3.4.1 – Train operators to interpret system explanations and to recognise required human intervention Example : Include exercises where operators learn correct object placement and respond appropriately to alerts such as “Obstacle detected” or “Localization lost.” They will need to interpret system explanations and recognize when human intervention is required, for example by responding appropriately to the system's messages and deciding on the correct action to undertake, ensuring timely and accurate human intervention.
	T3.4.2 – Train understanding of interface rationale and feedback signals. Example – Include practice interpreting interface elements, indicator lights, pop-up messages, and start/rearm confirmations. This way Operators have the chance to learn the purpose and meaning of interface elements, ensuring correct interpretation of system feedback in the future.
	T3.4.3 – Train correct interpretation of signals. Example – Provide exercises for interpreting light indicators, pop-ups, and error-reset procedures to ensure accurate, safe responses. For example, a red light on the workstation signals a critical error requiring

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	immediate intervention, a yellow light indicates a warning that must be monitored, and pop-up messages provide step-by-step instructions to resolve minor issues. This ensures operators respond accurately and safely to system cues.
T3.5 - Train on system transparency: AI/robot capabilities and limits Ensure operators understand which tasks are autonomous, which require human intervention, and the system's limitations to avoid overreliance.	
T3.6 -Use incremental training for system/robot/AI interaction Progressively train operators from basic manual interactions to single-step and then multi-step automated workflows, gradually increasing complexity to build competence and confidence.	
4. Skills, roles and responsibilities	
T4.1 – Provide differentiated training depending on user experience. Offer training paths that adapt to operator experience, ensuring novice users receive additional guidance while experienced users can work in advanced modes.	
T4.2 – Train operators to maintain and execute key manual skills in mixed-mode workflows. Integrate structured hands-on exercises to preserve essential manual skills and maintain operator readiness when transitioning between automated and manual tasks.	
5. Ethics and Liability	
T5.1 – Train operators to document validations, overrides, and ethical concerns consistently. Emphasize standardised documentation practices that support transparent review and auditing. Teach operators to record the rationale behind validations, overrides, and deviations, ensuring accountability and compliance.	
T5.2 – Train when and how to use overrides responsibly. Ensure operators learn the thresholds and conditions under which overrides are required, safe, and justified. Provide exercises demonstrating safe stops, controlled restarts, and appropriate manual interventions.	
T5.3 – Train operators on how and when to report ethical or safety-relevant anomalies. Teach clear criteria to identify when anomalies must be escalated to supervisors, safety officers, or compliance roles.	
T5.4 – Train operators to recognise when they hold ultimate responsibility, regardless of AI suggestions. Reinforce safety-first decision-making, highlighting that AI recommendations must always be validated, not merely accepted.	
T5.5 – Train operators on data protection and on maintaining ethical conduct when interacting with AI systems. Teach ethical interaction principles, such as avoiding misuse of system capabilities. Include guidance on secure handling of logs, confidentiality, and responsible data management.	

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5. Conclusions

The Skills Transformation Map and the Human-Centric Design and Training Guidance are the results of the entire analysis and validation process conducted over the three years of the project. These outputs are intended to serve as useful tools to support the multidisciplinary design teams involved in Industry 5.0 projects, ensuring that humans are properly considered throughout the design process. Overall, the Guidance establishes a practical, context-sensitive foundation for integrating Industry 5.0 technologies into complex manufacturing workflows. It ensures that the adoption of advanced automation is not approached solely as a technical challenge, but as a socio-technical process in which human roles, capabilities, and responsibilities remain central. When combined with ongoing refinement, iterative testing, and the systematic incorporation of user feedback, the Guidance can continue to evolve into a comprehensive tool for supporting the long-term success, acceptance, and sustainability of human–AI–robot collaboration in industrial environments.

Considerations and opportunities for future research

The Skills Transformation Map and the Human-Centric Design and Training Guidance are grounded in extensive field observations, expert assessments, and testing of HARTU's solution, providing a solid foundation for human-centred design and training practices. While they have been developed based on the HARTU use cases, it is worth noting that the evidence base reflects a selected set of operational contexts and organisational configurations. Expanding the range of contexts in future research could provide further insights into the diversity of manufacturing environments and workforce profiles. Similarly, early-stage testing (TRL 6) offers valuable indications, and as the technological components continue to evolve, additional behaviours, interaction patterns, and functionalities may emerge, offering further opportunities to refine and enrich the Guidance.

The current version of the Guidance already offers practical support for human-centric design and training. Looking ahead, several avenues exist to enhance its applicability and impact. Future iterations could incorporate insights from a wider variety of use cases, strengthening understanding of workflow diversity and operator variability across manufacturing settings. As HARTU's technological components mature, the Guidance can be adapted to address new functionalities—such as adaptive interfaces, predictive maintenance assistance, or AI-driven decision support—ensuring they are fully aligned with human-centred principles.

There is also potential to enrich the Guidance with scenario-based recommendations, providing practitioners with concrete examples of best practices for both standard and non-standard operations. Developing modular, role-specific guidance packages could further support tailored adoption, aligning responsibilities, skills, and escalation paths with organisational needs while addressing accessibility, workload variability, and training requirements across diverse operator profiles.

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6. References

[1] European Commission, "Industry 5.0," research-and-innovation.ec.europa.eu, 2024. https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/industry-50_en (accessed Nov. 21, 2025).

[2] C. Cimini, D. Romero, R. Pinto, and S. Cavalieri, "Task Classification Framework and Job-Task Analysis Method for Understanding the Impact of Smart and Digital Technologies on the Operators 4.0 Job Profiles," Sustainability, vol. 15, no. 5, p. 3899, Feb. 2023, doi: https://doi.org/10.3390/su15053899.

[3] Team DigitalDefynd, "Career in Manufacturing: How to Be Ready for Industry 5.0?," DigitalDefynd, Apr. 10, 2025. https://digitaldefynd.com/IQ/how-to-be-ready-for-industry-5-0/ (accessed Nov. 21, 2025).

[4] D. Crawley, "Developing the Skills and Culture Needed for Industry 5.0 | Industrial Decarbonization Network," Industrial Decarbonization Network, Apr. 13, 2022. https://www.industrialdecarbonizationnetwork.com/digital-transformation-1/interviews/developing-the-skills-and-culture-needed-for-industry-50

[5] "Home," esco.ec.europa.eu. https://esco.ec.europa.eu/en

[6] "Cedefop," Cedefop. https://www.cedefop.europa.eu/en

[7] "Manufacturing Skills Observatory and Competencies Framework," EIT Manufacturing, Oct. 06, 2021. https://www.eitmanufacturing.eu/news-events/activities/manufacturing-skills-observatory-and-competencies-framework/ (accessed Nov. 21, 2025).

[8] "TRAILS Project," Trails-project.eu, 2025. https://www.trails-project.eu/ (accessed Nov. 21, 2025).

[9] I. Khaouja, I. Kassou, and M. Ghogho, "A Survey on Skill Identification From Online Job Ads," IEEE Access, vol. 9, pp. 118134–118153, 2021, doi: https://doi.org/10.1109/access.2021.3106120.

[10] C. Sleeman, "An Open and Data-driven Taxonomy of Skills Extracted from Online Job Adverts," Economic Statistics Centre of Excellence (ESCoE) Discussion Papers, Aug. 2018. https://ideas.repec.org/p/nsr/escoed/escoe-dp-2018-13.html (accessed Nov. 21, 2025).

[11] D. Mourtzis, J. Angelopoulos, V. Siatras, and N. Panopoulos, "A Methodology for the Assessment of Operator 4.0 Skills based on Sentiment Analysis and Augmented Reality," Procedia CIRP, vol. 104, pp. 1668–1673, 2021, doi: https://doi.org/10.1016/j.procir.2021.11.281.

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