

HUMAN-AI COLLABORATION DESIGN FOR MANUFACTURING

DESIGN DIMENSION 1 - PRE-DESIGN ACTIVITIES

Pre-design activities refer to the actions that should be addressed before collaboration design begins. They establish the goals, context, organisational readiness, stakeholder needs, and ethical foundations that guide subsequent design decisions.

PC1: Define the collaboration goal, expected benefits, and evaluation metrics

Clarify why the collaboration is needed and what outcomes it should achieve. / Goals influence task design, team requirements, interaction design, performance expectations, and evaluation criteria.

Considerations

- what problem is being solved
- what value is expected from the collaboration
- what are the success criteria
- what benefits should be created for workers
- how will outcomes be evaluated

PC2: Analyse the deployment context and select appropriate technologies and interaction methods

Ensure the collaboration design fits the operational environment.

Considerations

- what environmental needs and constraints there are?
- which safety requirements are relevant
- what are the existing work practices
- are there technological constraints

PC3: Assess organisational readiness

Understand whether the organisation, workforce, technologies, and processes are prepared for the intended collaboration.

Considerations

- current organisational capabilities
- existing work processes
- workforce competencies
- previous AI experience
- data availability and quality
- organisational AI openness and support

PC4: Involve users and stakeholders in design

Ensure the collaboration reflects real work needs and worker perspectives.

Considerations

- include end-users and other relevant stakeholders throughout the development process
- understand worker needs and expertise
- capture tacit work knowledge by including the experienced human workers to the design
- use participatory design approaches

PC5: Use human-centred design approach throughout the collaboration design and deployment

Support feasible and effective human-AI solutions.

Considerations

- combine technical and human-centred expertise

- prototype early
- validate with users
- refine through iteration and end-user feedback
- balance technical feasibility and worker needs

PC6: Address ethics and human values from the beginning

Ethical concerns and human values should be treated as design requirements, and they should be considered before collaboration implementation to ensure responsible and human-centred collaboration.

Considerations

- human augmentation instead of automation
- human well-being
- fairness and bias
- privacy
- safety
- worker autonomy

COLLABORATION DESIGN GUIDELINES

DESIGN DIMENSION 1 - Task configuration

Task configuration refers to how collaborative work is structured, allocated, and coordinated between human and AI collaborators. It defines what work is performed, how responsibilities are distributed, and how meaningful human involvement is maintained.

Guideline1: Clearly define and communicate collaborative task structures and collaborators' roles and responsibilities in it.

Successful collaboration requires collaborators to understand what needs to be done, who is responsible for each activity, and how individual contributions support shared goals.

Design considerations

- define collaboration goals and related activities explicitly
- define and structure collaborative tasks
- specify roles, responsibilities, and contributions for each collaborator
- communicate roles, responsibilities and contributions clearly to the collaborators
- communicate task progress and collaboration status transparently

Guideline2: Allocate work according to task requirements and collaborator capabilities

Appropriate task allocation allows AI to support human work while improving performance, safety, ergonomics, and well-being.

Design considerations

- allocate activities and responsibilities according to collaborator capabilities, knowledge, and expertise
- use AI to support repetitive, hazardous, physically demanding, or cognitively intensive tasks
- preserve activities requiring human judgement, contextual understanding, creativity, and expertise
- consider how task allocation affects worker well-being and workload
- reassess allocations as collaborator capabilities and technologies evolve

Guideline3: Maintain meaningful human involvement and agency

Human-centred collaboration requires workers to remain active contributors rather than passive observers. Meaningful involvement supports engagement, skill retention, accountability, trust, and worker well-being.

Design considerations

- keep humans involved in decision-making and task execution where appropriate
- preserve human oversight and authority over collaboration outcomes
- avoid collaboration arrangements that reduce work to passive monitoring
- design tasks that utilise and develop human competencies
- ensure workers understand how their contributions influence collaboration outcomes

Guideline4: Design for adaptive task allocation

Manufacturing environments are dynamic, requiring task configurations to evolve in response to changing conditions, technologies, collaborators, and operational requirements. // Manufacturing environments, tasks, technologies, and collaborators continuously change

Design considerations

- allow task allocations to adapt to changing situations
- support dynamic adjustment of roles and responsibilities as situations change/when required
- enable collaborators to assist each other when circumstances change
- design mechanisms for reallocating responsibilities during disruptions
- monitor collaboration effectiveness and adjust task structures when necessary

DESIGN DIMENSION 2 - Collaboration team

The collaboration team refers to the human and AI collaborators working together towards a shared objective. It focuses on assembling teams whose complementary capabilities match the requirements of the collaborative task.

Guideline5: Build collaboration teams by matching task requirements with complementary human and AI capabilities

Skills demand should be derived from the task requirement, and the team should be assembled to match those requirements. Human-AI teams perform best when collaborators contribute according to their individual strengths and limitations.

Design considerations

- align roles and responsibilities with collaborator capabilities
- use AI to complement human expertise rather than duplicate it
- consider how capabilities may evolve over time
- review role allocations as tasks and technologies change

Guideline6: Support cooperative and mutually beneficial teaming

Effective collaboration depends on collaboration being perceived as a cooperative partnership rather than a competitive or purely supervisory relationship.

Design considerations

- Enable all collaborators to contribute meaningfully to shared goals
- Support reciprocal assistance between human and AI collaborators
- Encourage collaborative rather than adversarial interaction patterns
- Design interactions that reinforce a sense of teamwork

DESIGN DIMENSION 3 - Skills and skill development

Skills and skill development refer to the competencies required to perform collaborative tasks and to work effectively with AI. This dimension addresses both task-specific expertise and AI collaboration literacy while supporting the preservation and development of human expertise.

Guideline7: Ensure collaborators possess the skills required for the task

Effective collaboration depends on human and AI collaborators possessing sufficient knowledge, expertise, and capabilities to perform their assigned responsibilities.

Design considerations

- identify the collaborators' skills and strengths
- match task demands with collaborator skills
- consider domain expertise and contextual knowledge requirements
- ensure collaborators can fulfil their assigned responsibilities
- avoid assigning tasks beyond collaborator skills
- reassess skill requirements as tasks evolve

Guideline8: Support AI collaboration literacy

Human collaborators require specific AI-related skills to collaborate effectively with AI beyond those needed to perform the task itself.

Design considerations

- help humans to understand AI capabilities and limitations
- support easy AI outputs and recommendations evaluation
- enable informed trust and reliance decisions
- facilitate effective communication with AI collaborators
- make expectations regarding AI use explicit (manage the expectations by giving correct information)

Guideline9: Design collaboration to preserve and develop human expertise

Human-AI collaboration should strengthen rather than erode human capabilities over time.

Design considerations

- maintain active human participation in collaboration
- avoid excessive reliance on AI recommendations
- create opportunities for learning through collaboration
- support development of human expertise and judgement
- monitor potential deskilling effects

DESIGN DIMENSION 4 - AI characteristics

AI characteristics refer to the properties and behaviours of the AI collaborator that enable effective human-AI collaboration. This includes transparency, explainability, adaptability, and proactivity that support human understanding and appropriate collaboration.

Guideline10: Design AI collaborators that are understandable to human collaborators

Human collaborators must be able to understand AI behaviour, reasoning, capabilities, limitations, and uncertainty sufficiently to support effective collaboration, informed decision-making, and appropriate reliance.

Design considerations

- make AI actions, current state, capabilities, limitations, and uncertainty visible to human collaborators (transparency)
- explain why AI recommendations, decisions, or actions were produced and how they relate to the current task context (explainability)
- explain unexpected behaviour, errors, and failures (explainability)
- adapt explanations to user expertise and situational needs

Guideline11: Design adaptive AI collaborators

Human-centred and effective collaboration requires AI to adjust its behaviour to changing tasks, environments, operational conditions, and human collaborators.

Design considerations

- adapt to worker capabilities and expertise
- adapt to individual preferences and work styles
- adjust behaviour according to situational requirements

- learn from collaboration experiences and feedback
- modify support strategies as collaboration needs evolve

Guideline12: Design proactive AI collaborators

AI should actively contribute to collaboration by identifying relevant information, emerging issues, and support opportunities rather than only responding to explicit requests.

Design considerations

- Notify users about important events and changes.
- Communicate emerging risks and anomalies.
- Suggest relevant actions or solutions proactively.
- Direct attention to critical information when necessary.
- Balance proactivity with avoiding unnecessary interruptions.

DESIGN DIMENSION 5 - Communication and interaction

Communication and interaction refer to how human and AI collaborators exchange information, coordinate activities, and develop mutual understanding throughout the collaboration. Effective communication supports coordination and shared understanding.

Guideline13: Design communication to support coordination and collaboration

Human-AI collaboration depends on effective information exchange that enables collaborators to coordinate activities, monitor progress, exchange feedback, and work towards shared goals.

Design considerations

- Support bidirectional information exchange between collaborators
- Communicate task-relevant information clearly
- Enable feedback throughout the collaboration process
- Support coordination of actions and responsibilities
- Ensure communication contributes to collaboration goals

Guideline14: Support mutual understanding between collaborators

Successful collaboration requires human and AI collaborators to develop sufficient understanding of the task, environment, collaboration process, and each other's intentions and actions.

Design considerations

- Support awareness of each collaborator actions and intentions, and of task progress
- Allow users to request additional explanations, rationales, or transparency information when needed
- Enable AI to model and interpret human intentions and situational needs
- design mechanism for bidirectional information exchange to coordinate actions
- provide feedback loops that allow collaborators to monitor, evaluate, and adjust their actions.

Guideline15: Design adaptive and multimodal communication

Communication needs vary according to tasks, environments, user characteristics, and operational constraints. Effective collaboration requires flexible communication mechanisms that adapts to user and contextual needs.

Design considerations

- Use communication modalities suitable for the work environment
- Support multiple interaction channels when beneficial
- Adapt communication to user capabilities and preferences
- Consider workload and operational constraints
- Select interaction mechanisms appropriate for the task context

Guideline16: Design information delivery to be timely, context-aware, and actionable

The value of information depends not only on its content but also on when and how it is delivered. Timely and proactive communication can improve coordination, reduce workload, and support decision-making.

Design considerations

- balance information availability with cognitive workload to avoid information overload
- prioritise important information
- support context-aware information delivery by adapting notifications, alerts, and information presentation to the current task
- notify users of emerging issues and anomalies
- provide information when it is most useful for the task execution
- avoid unnecessary interruptions during critical tasks

DESIGN DIMENSION 6 - Enabling infrastructure

The enabling infrastructure refers to the socio-technical infrastructure that supports human–AI collaboration. It provides the mechanisms for coordination, information management, communication, and situational awareness required for effective collaboration.

Guideline17: Design infrastructure that enables coordinated and informed collaboration

Human-AI collaboration depends on infrastructure that connects collaborators, tasks, systems, and the manufacturing environment, enabling coordinated action and decision-making.

Design considerations

- integrate information from collaborators, systems, tasks, and environment
- support coordination across human and AI activities
- enable collaboration across physical and digital environments
- design infrastructure that can evolve alongside changing manufacturing needs
- support resilient collaboration during disruptions and changes

Guideline18: Support situational awareness and human oversight

Effective collaboration requires collaborators, particularly human workers, to maintain awareness of tasks, system states, environmental conditions, and AI activities.

Design considerations

- provide visibility into task status and collaboration progress
- communicate relevant system and environmental information
- support awareness of AI actions and current status
- present information that supports informed intervention and oversight
- make uncertainty, risks, and critical events visible when relevant

Guideline19: Design multimodal and adaptive information infrastructures

Human-AI collaboration relies on the information availability, quality, security, and accessibility.

Design considerations

- integrate information from relevant sources
- present information in accessible and understandable forms
- support information sharing between collaborators
- reduce information overload
- ensure critical information is salient and easy to find

DESIGN DIMENSION 8 - ORGANISATIONAL RESPONSIBILITIES

Organisational context refers to the structures, practices, and policies that enable, constrain, and shape human-AI collaboration in manufacturing environments. Organisational support is essential for the successful AI adoption.

OR1. Support workforce development for human-AI collaboration

Organisations should ensure that workers possess the competencies required to collaborate effectively with AI technologies and adapt to evolving manufacturing environments.

Responsibilities

- provide continuous workforce training
- support upskilling and reskilling initiatives
- promote AI literacy throughout the organisation
- integrate learning opportunities into everyday work
- support adaptation to changing technologies and work practices

Workers should be prepared to:

- use AI systems appropriately
- interpret AI outputs and recommendations
- understand AI capabilities and limitations
- evaluate AI-generated information critically
- collaborate effectively with AI in work tasks

OR2. Establish data governance and management practices

Human-AI collaboration relies on trustworthy, accessible, and well-managed data. Organisations are responsible for ensuring that AI systems have access to suitable data while protecting workers' rights and privacy.

Responsibilities

- ensure availability of relevant data
- monitor and maintain data quality
- define data ownership and access rights
- protect information security
- safeguard worker privacy
- communicate how data is collected, stored, and used

OR3. Define governance, accountability, and responsible AI practices

Organisations should establish clear governance structures that define responsibilities, accountability, and acceptable AI use within manufacturing operations.

Responsibilities

- define accountability for AI-supported decisions and outcomes
- establish clear roles and responsibilities
- ensure compliance with regulations and organisational policies
- monitor fairness and potential bias in AI
- promote responsible and ethical AI use
- ensure safe deployment and operation of AI technologies

OR4. Promote human-centred organisational values

Organisations should ensure that AI adoption aligns with human-centred values and supports worker well-being, safety, and meaningful work.

Responsibilities

- prioritise worker safety and well-being
- support meaningful and engaging work
- promote augmentation rather than replacement of human workers
- consider long-term sustainability of workforce development
- align AI adoption with organisational and societal values