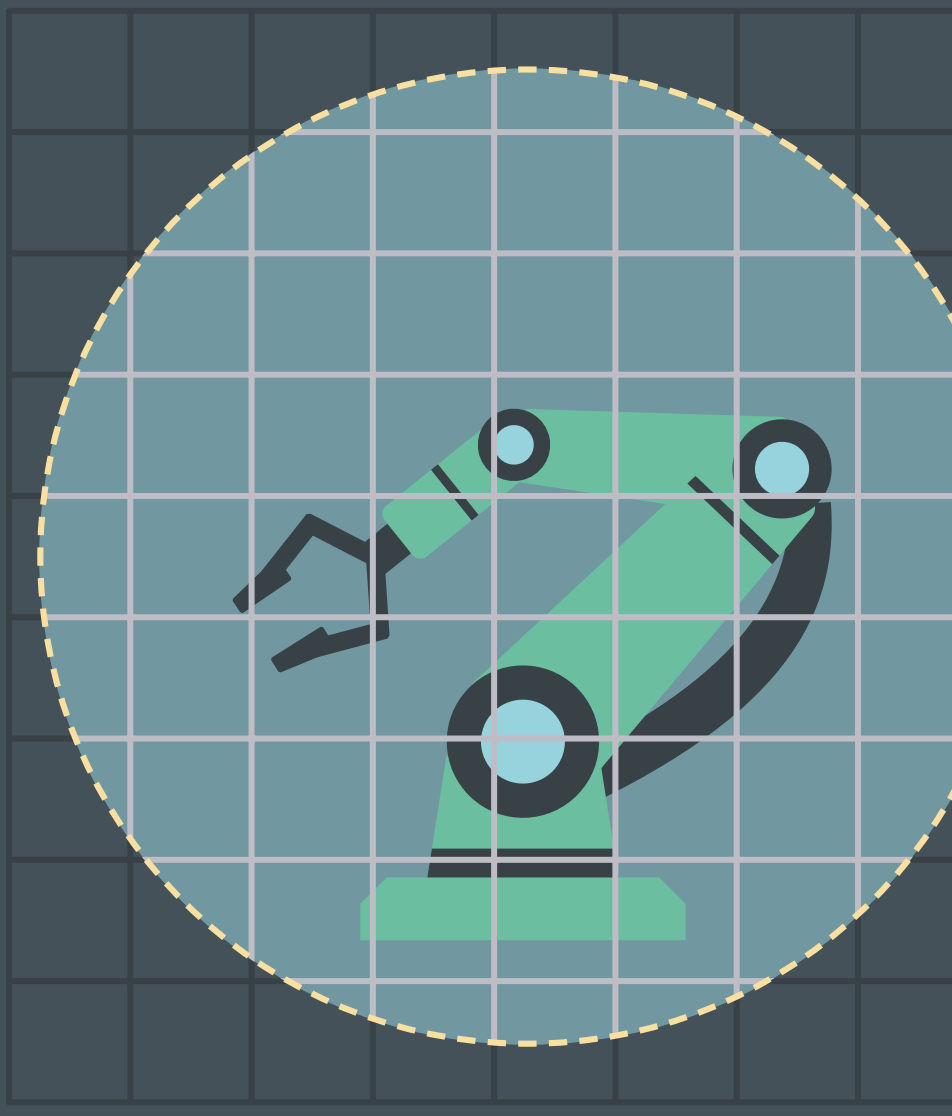
Guidelines for Safe Collaborative Robot Design and Implementation

Designing a Safe Cobot Workplace



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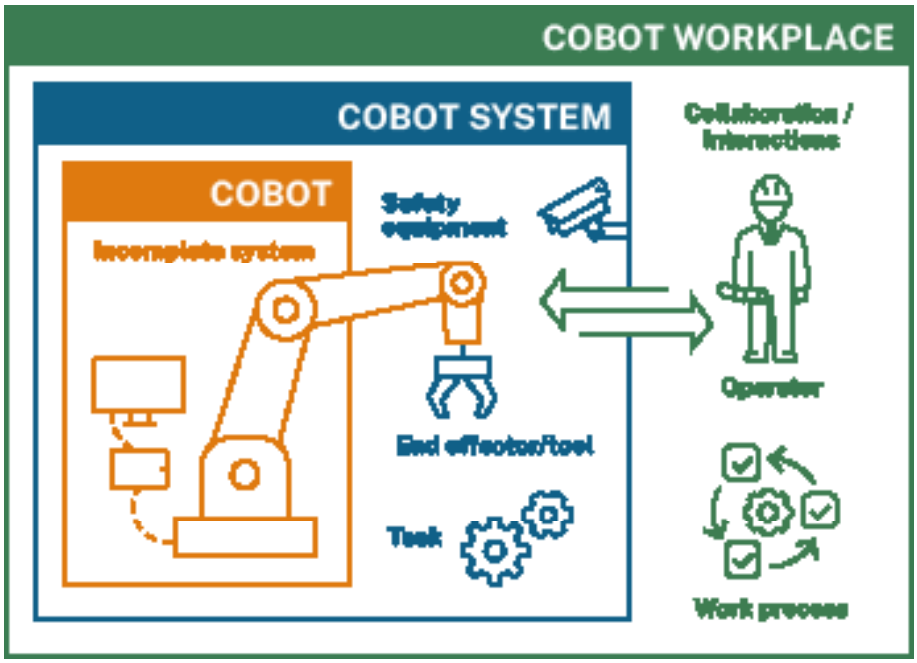
NSW GOVERNMENT

Designing a Safe Cobot Workplace

Document purpose

This document outlines the responsibilities of each stakeholder throughout the cobot lifecycle, with a main focus on integrators and administrative staff.



Relevant cobot lifecycle phases

Product Development & Manufacturing	Cobot Workplace Planning	Installation & Commissioning	Use Phase & Operation	Maintenance & Adjustments
Design principles for facilitating safe use of cobots and equipment	Guide design of cobot workplace	Guide for safe installation including work processes, equipment and training	Principles for safe use of cobot systems	Ensure changes to not jeopardise cobot workplace safety

Who should use this document?

- Cobot manufacturers
- Distributors and suppliers
- ✓ Operators
- Co-workers and visitors
- Manufacturers of third-party equipment
- ✓ Integrators
- Beneficiary users
- ✓ Managers and administrative staff

Where does this document fit into the overall Guidelines?

Guidelines for Safe Collaborative Robot Design and Implementation

PLANNING OF UPCOMING WORKPLACE

- Guidance on Safe Human-Cobot Interaction
- ✓ Designing a Safe Cobot Workplace

ASSESSMENT OF EXISTING WORKPLACE

- Cobot Workplace Safety Checklist
- Cobot Work Health and Safety Risk Assessment

Cobot Safety Flyers

Contents

How to use this document

This document outlines the roles and responsibilities of various stakeholders throughout the entire lifecycle of a cobot system, with a particular focus on managers, administrative staff, and integrators. Readers can:

a. Understand their role based on the activities they conduct within their business

b. Navigate the document to read about the lifecycle that is most relevant to them

c. Read and understand the tasks they are responsible for, as well as clarify expectations related to other stakeholders' responsibilities

Note: These guidelines are not intended to replace the relevant and necessary standards that apply to your workplace. They are intended to support readers who wish to adopt cobots in their workplace.

a. How to understand your role

A person's role within a company may cover one or more distinct groups, or their job may not require them to adopt all responsibilities listed below. Table 1 provides a general description of the main roles in an effort to support readers to recognise their responsibilities.

Table 1: Cobot roles and definitions

You're considered a:	If you are responsible for one or more of the following:	If you are NOT responsible for one or more of the following:
Cobot manufacturer	• Researching and developing (R&D) the cobotic arm • Manufacturing the physical cobot arm	n/a
Third-party manufacturer	• Researching and developing (R&D) accessories, equipment (including end effectors), and safety peripherals • Manufacturing accessories, equipment (including end effectors), and safety peripherals	n/a
Distributors and suppliers	• Selling cobot arms and/or third-party components • Providing implementation and integration support	n/a
Integrators[1]	• Completing the cobot system by combining the cobot arm with various equipment • Integrating a cobot into an existing workplace • Configuring hardware and software systems • Designing and programming the task application for the cobot and operators • Providing post-implementation support for troubleshooting and maintenance during use, operation, maintenance, and adjustments	n/a
Operators	• Directly physically interacting and working with the machine to complete tasks in the same workspace • Supervising the cobot task • Reporting hazards to managers and administrative staff	n/a
Passive users	• Physically interacting with the cobot in the same workspace • Performing the task with operators and/or cobots (e.g. a patient using a cobot during physical rehabilitation)	• Controlling the cobot system • Supervising the cobot system
Co-workers and visitors	n/a	• Controlling the cobot system • Supervising the cobot system • Working in the cobot workspace
Managers & administrative staff	• Making the decision to purchase and/or install a cobot system into your workplace • Conducting the operational processes in which the cobot will fit in • Establishing and& maintaining safe human-cobot collaborative workplaces • Establishing maintenance policies	• Interacting with the physical cobot or the task application.

1 Integrators can be a third-party company, a service provided by the supplier, or roles assigned to employees of the user company. Regardless of their company of origin, the integrator's responsibilities do not change. Therefore, for the purpose of this document, no distinction is made.

b. How to navigate through the lifecycle stages

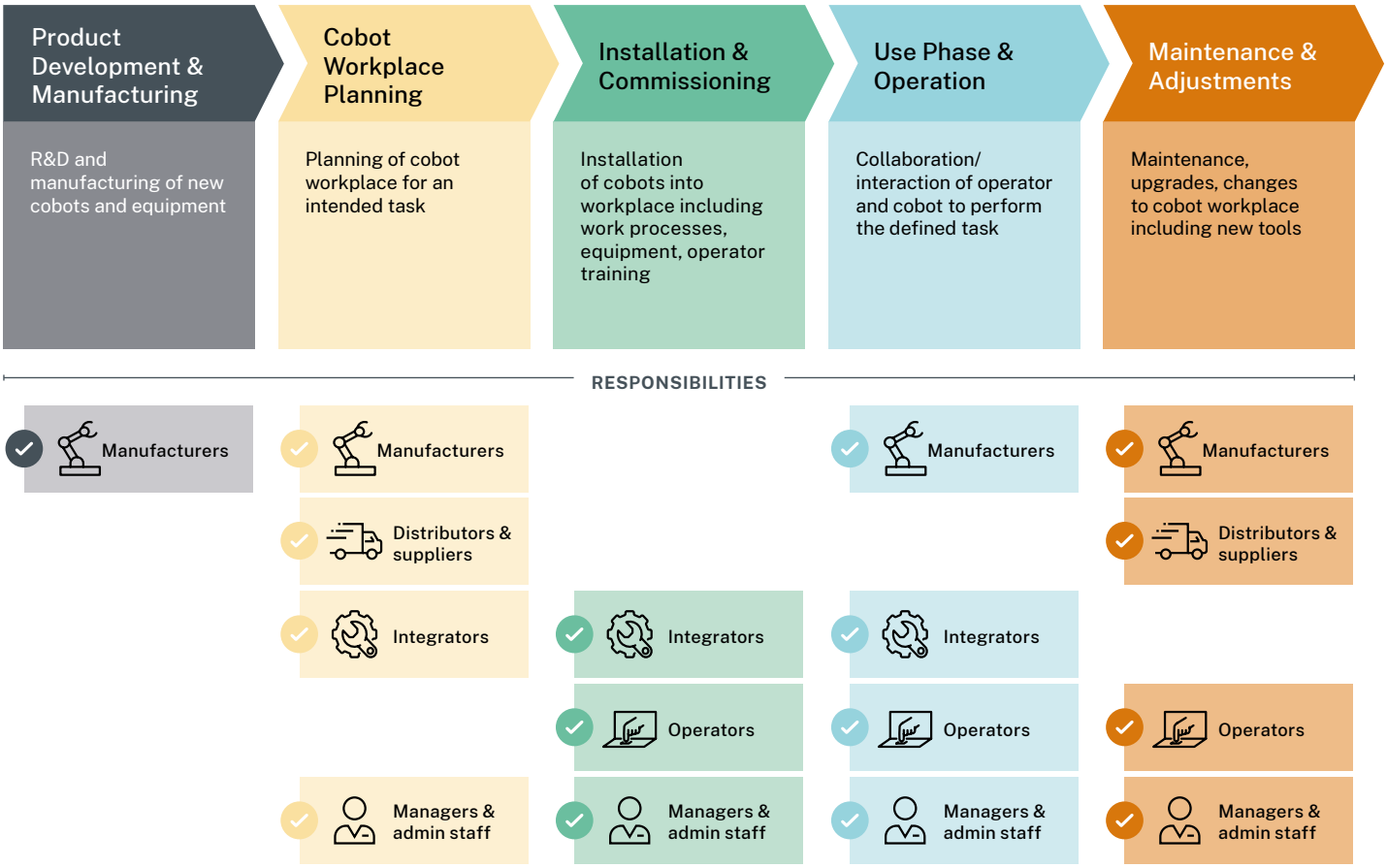
For each stage of the lifecycle of a cobot system, the document lists which stakeholder is responsible, accountable, consulted, or informed (RACI). Generally, there is at least one stakeholder responsible for each task, while others may have other roles.

R	**Responsible**	This stakeholder does the work and completes the task. Occasionally, the responsibility may be shared among stakeholders
A	**Accountable**	This stakeholder oversees the delegation of work and approval of deliverables
C	**Consulted**	This stakeholder reviews the deliverable and provides feedback
I	**Informed**	This stakeholder is expected to know and understand the state of a specific task

Based on the RACI mapping for each lifecycle phase, it is possible to identify which groups hold the most responsibilities and how these responsibilities shift through the various phases.

The document is structured by lifecycle stages, and readers can navigate to a specific stage by using the index and the colour coding as defined in Figure 1.

Figure 1: Stakeholders' responsibilities throughout the lifecycle



c. How to understand responsibilities

Table 2 list the required tasks to make cobot systems safe across the various lifecycle stages. Tasks are associated with the relevant stakeholders' responsibilities using the RACI mapping. The following sections of the document provide further description of the tasks listed in the tables.

R	**Responsible**	This stakeholder does the work and completes the task. Occasionally, the responsibility may be shared among stakeholders
A	**Accountable**	This stakeholder oversees the delegation of work and approval of deliverables
C	**Consulted**	This stakeholder reviews the deliverable and provides feedback
I	**Informed**	This stakeholder is expected to know and understand the state of a specific task

Table 2: Responsibilities for each stakeholder accross the entire lifecycle

Product development & manufacturing								
Task	**Manufacturers**				**Cobot users**			
	Cobot manufacturers	**Manufacturers of third-party equipment**	**Distributors and suppliers**	**Integrators**	**Operators**	**Beneficiary users**	**Co-workers and visitors**	**Managers and administrative staff**
Embed safety features according to the standards	**R**	**R**						
Ensure safety of hardware and software for both cobot and components	**R**	**R**						
Integrate safety sensors onto devices	**R**	**R**	**I**	**I**				
Adopt a user-friendly design	**R**	**R**		**C**	**C**		**C**	**I**
Facilitate the integration of components into the cobot	**C**	**R**		**C**				
Make maintenance processes easy	**R**	**R**						
Don't assume 'common sense' and clarify what components safety is guaranteed for	**R**	**R**	**A**		**C**		**C**	
Provide accessible and easy to understand technical documentation for integrators and users	**R**	**R**	**A**					

Cobot workspace planning

Task	Manufacturers		Distributors and suppliers	Integrators	Cobot users			
	Cobot manufacturers	Manufacturers of third-party equipment			Operators	Beneficiary users	Co-workers and visitors	Managers and administrative staff
Ensure transparency about how data is collected by the cobot during operation	R	R		R	C			A
Sell and market cobots as part-machines	C	C	R					I
Select safe cobot and End effectors, and integrate them in a safe way			A	R	I			A
Consult user groups when designing the workplace and allocate tasks				R	C	C		R
Conduct a risk assessment				R	C	C		A
Choose a safe location for the cobot system and ensure changes to the workspace do not generate new risks elsewhere				R	C	C		A
Establish clear and intuitive communication channels within the system and around the workplace				R	C	C		R
Include staff into decisions how to best integrate the cobot into existing workflows				A	C	C		R
Engage staff through appropriate training policies for both building knowledge and skills, and improving acceptance					C	C		R
Simulate the tasks within the workspace				R	C			I

Installation & commissioning

Task	Manufacturers		Distributors and suppliers	Integrators	Cobot users			
	Cobot manufacturers	Manufacturers of third-party equipment			Operators	Beneficiary users	Co-workers and visitors	Managers and administrative staff
Provide accessible documentation and/or support when requested by users and integrators	R	R	A	C	C			A
Consult operators during cobot installation				R	C	C		A
Address workspace-specific risks and set safety boundaries				R	C	C		R
Use various testing procedures to address hazards and account for all aspects including the psychological and ethical impact of cobots				R	C	C		I
Include multiple fail-safe safety measures to mitigate risks whenever part of the equipment cannot naturally revert to a safe condition in case of malfunction or breakdown				R				A
Educate company and operators on best practices in cybersecurity			R	R	I			I
Ensure the cobot system includes intuitive communication channels				R	C			A
Understand how to practice safe human-cobot collaboration and the potential implications of using a cobot in a non-collaborative manner			R	R	A			R
Measure the impact of not only physical factors but also psychological ones				R	C	C		R
Ensure that unauthorised persons cannot interact with the system.				R	I			R

Use phase & operation

Task	Manufacturers		Distributors and suppliers	Integrators	Cobot users			
	Cobot manufacturers	Manufacturers of third-party equipment			Operators	Beneficiary users	Co-workers and visitors	Managers and administrative staff
Provide user-friendly troubleshooting documentation	R	R	R	C	C			A
Notify users when the system needs to be updated or reconfigured	R	R		I	I			I
Allow the use of cobot only within the recommended settings				R	A	I	I	R
Follow the safety recommendations provided by manufacturers and integrators					A	I	I	R
Monitor workspace for co-workers and visitors that may be unaware of cobot and pause tasks if necessary					R		I	
Secure the system after each operation to prevent use by unauthorised persons.					R	I	I	
Troubleshoot in a safe manner and report any observed issues or concerns to administrative staff	I	I	I		R			C
Comply with the safety protocols and understand how to locate and initiate emergency stops and comply with the safety protocols						R	R	

Maintenance & adjustments

Task	Manufacturers		Distributors and suppliers	Integrators	Cobot users			
	Cobot manufacturers	Manufacturers of third-party equipment			Operators	Beneficiary users	Co-workers and visitors	Managers and administrative staff
Advise for changes with software update	R	R	I	I	I			I
Sell and market as cobots and other equipment as part-machine	C	C	R					I
Maintain the system, both hardware and software, and their relative updates					R			R
Follow testing protocols whenever any system change occurs								
Ensure the software system gets updated correctly and conduct tests prior to operation if the system is affected by substantials changes					I			R
Conduct a risk assessment and testing procedures whenever a change to the workspace occurs				R	C	C		R
Conduct routine risk assessments					I	I	I	R
Establish routine cybersecurity checks					I	I	I	R

Product Development & Manufacturing

Table 3 provides an overview of key tasks of this cobot lifecycle phase and relevant stakeholder roles and responsibilities.

Table 3: Responsibilities in the product development and manufacturing phase

Task	Manufacturers		Distributors and suppliers	Integrators	Cobot users			
	Cobot manufacturers	Manufacturers of third-party equipment			Operators	Beneficiary users	Co-workers and visitors	Managers and administrative staff
Embed safety features according to the standards	R	R						
Ensure safety of hardware and software for both cobot and components	R	R						
Integrate safety sensors onto devices	R	R	I	I				
Adopt a user-friendly design	R	R		C	C		C	I
Facilitate the integration of components into the cobot	C	R		C				
Make maintenance processes easy	R	R						
Don't assume 'common sense' and clarify what components safety is guaranteed for	R	R	A		C		C	
Provide accessible and easy to understand technical documentation for integrators and users	R	R	A					
Provide accessible and easy to understand training documentation for users	R	R	A					

MANUFACTURERS

'Manufacturers' refers to manufacturers and manufacturers of third-party equipment and safety peripherals.

1. Embed safety features according to the standards

Manufacturers are legally responsible to design cobots in line with the standard ISO 10218-1:2011. To be classified and labelled a cobot, the system is expected to include one or more of the following four safety modes: safety-rated monitoring stop, hand guiding, speed and separation monitoring, and/or power and force limiting. In addition, robots designed for collaborative applications must indicate when they are operating in a collaborative mode. Similarly, end effectors, accessories, and safety peripheral manufacturers are required to comply with cobot specifications and relevant technical standards.

2. Ensure safety of hardware and software for both cobot and components

Cobot manufacturers should ensure the safety of both hardware and software. Safe hardware should prevent risks generated by potential malfunctions of the cobot system (see examples in Table 4 and full list in the Introduction document, Table 3). The cobot software should also be developed in a safe manner. To protect data and prevent potential cyber-attacks, data should be encrypted and protected by appropriate IT mechanisms.

Table 4: Examples of hazards generated by unsafe cobot hardware

Hazard	Description
Systemic or component malfunction	Malfunctions including force transients, inhomogeneous interfaces, or system failure can follow, increasing the risk of physical harm to humans or damage to the cobot system. Mechanical components of the system breaking or loosening can also increase the risk of physical harm.
Electrical hazard	Electrical hazards, such as confusion with voltages within a system, broken or disconnected electrical connectors, loss of variation of power, human contact with electrical connectors, may cause physical harm to the user, or damage components of the cobot system.
Chemical hazard	The exposure to chemicals, such as creation of fumes, explosive atmosphere, or extreme temperature, can physically harm humans.
Insufficient safety measures	The lack of safety measures, such as not covering certain hazardous areas or inadequate safety limits (speed or distance related), expose humans to increased physical risks.

Similarly, the safety of components must be considered as important as the safety of the part machine. Third-party manufacturers should design end effectors in a way that facilitates the safety of the cobot system and considers ergonomics. As for cobots, end effectors can be responsible for creating inherent risks (see examples in Table 5 and the Introduction document, Table 3). To reduce end effector related risks, safety measures should not only be part of the cobot but also embedded in the end effectors themselves. Examples include sensors and emergency stop mechanisms.

Table 5: Examples of risks generated by End effectors

Harm	Hazard
Burn	Welding, chemicals
Cut	Sharp edges
Injury	Loss of workpiece, protrusion

3. Integrate safety sensors onto devices

To ensure that the entire physical machine can respond and react to unexpected human interaction, embedding safety sensors onto end effectors ensures that the entire cobot can conduct an emergency stop in case of emergency.

4. Adopt a user-friendly design

To ensure safety, cobot features should be user-friendly, including interaction mechanisms (input and output), maintenance, and calibration. This includes developing and including build-in intuitive programming techniques such as hand-guided operation into all models, and ensuring that the user-interfaces are easy-to-understand and not confusing for non-technical users.

Similarly, end effectors should also be designed in a user-friendly and intuitive manner. End effector manufacturers should develop products that can be easily integrated and adopted into existing systems for cobots. Accordingly, the design should ensure that the product complies with the larger cobot system's emergency stop mechanisms and related safety modes.

5. Facilitate the integration of components into the cobot

Ensure that products can be easily integrated and adopted into existing systems for the cobot. Accordingly, the design should ensure that the product complies with the larger cobot system's emergency stop mechanisms and related safety modes.

6. Make maintenance processes easy

Relevant features, such as sensors, should be developed to allow easy access and easy maintenance to ensure safety also during future operational phases.

7. Don't assume 'common sense' and clarify what components safety is guaranteed for

Manufacturers should clearly communicate to distributors, suppliers, and customers that cobots are sold as incomplete machines. A part machine cobot comprises four components: the manipulator (arm), controller / cabinet (computer and drivers), connecting cable between manipulator and cabinet, and the teach pendant (human interface). Manufacturers should make clear in the sales process that at this stage, the cobot safety is only guaranteed for specific components. They should also direct customers to resources and services that can assist them in "completing" the machine.

8. Provide accessible and easy to understand *technical* documentation for integrators and users

Ensure that any support documentation for installation, commissioning, maintenance, and operation is easy to navigate and understand for integrators and users with technical experience working with cobots.

9. Provide accessible and easy to understand *training* documentation for users

Training documentation about how to operate and use the cobot and/or other equipment should be easy to access and understand for non-technical users. To support training, along with the full manual, manufacturers should provide easy-to-read fact sheets to guide users through operating, troubleshooting, and cleaning the cobot system. These documents can be then attached into the workspace to assist operators and visitors. Training should also use a blend of teaching methods, including videos and case studies, to ensure that operators have hands-on experience with cobots prior to handover.

DISTRIBUTORS & SUPPLIERS

1. Provide accessible documentation

Distributors and suppliers must sell cobots and related equipment ensuring that any support documentation is attached and adheres to a customer's right-to-repair.

Cobot Workplace Planning

The following table provides an overview of key tasks of this cobot lifecycle phase and relevant stakeholder roles and responsibilities.

Table 6: Responsibilities in the cobot workspace planning phase

Task	Manufacturers		Distributors and suppliers	Integrators	Cobot users			
	Cobot manufacturers	Manufacturers of third-party equipment			Operators	Beneficiary users	Co-workers and visitors	Managers and administrative staff
Ensure transparency about how data is collected by the cobot during operation	R	R		R	C			A
Sell and market cobots as part-machines	C	C	R					I
Select safe cobot and End effectors, and integrate them in a safe way			A	R	I			A
Consult user groups when designing the workplace and allocate tasks				R	C	C		R
Conduct a risk assessment				R	C	C		A
Choose a safe location for the cobot system and ensure changes to the workspace do not generate new risks elsewhere				R	C	C		A
Establish clear and intuitive communication channels within the system and around the workplace				R	C	C		R
Include staff into decisions how to best integrate the cobot into existing workflows				A	C	C		R
Engage staff through appropriate training policies for both building knowledge and skills, and improving acceptance					C	C		R
Simulate the tasks within the workspace				R	C			I

MANUFACTURERS

'Manufacturers' refers to manufacturers and manufacturers of third-party equipment and safety peripherals.

1. Ensure transparency about how data is collected by the cobot during operation

Cobots are complex systems that combine hardware and software and allow companies and users to make informed business decisions. Along with the technical documentation, manufacturers should clearly communicate how data is collected and stored during collaborative operations.

DISTRIBUTORS & SUPPLIERS

1. Sell and market cobots as part-machines

Distributors and suppliers should ensure that customers understand that cobots are marketed and sold as part-machines. Accordingly, they should clarify what components are assured to be safe and what safety requirements should be addressed for the cobot to be considered a complete machine.

INTEGRATORS

1. Select appropriate cobot and End effectors, and integrate them in a safe way

Choosing the right system for the right application is what ensures the safety of the system (see *Safe Human-Cobot Interaction Guidance*). This not only applies to the cobot itself, but also to the end effectors and the overall component integration. End effectors should be selected to allow safe collaboration and intended for collaborative uses. When integrating all components to build the collaborative system, it is important to consider architectural and procedural redundancy in case unsafe devices are requested in safety sensitive procedures. The software component should also be made safe by ensuring protection from external cyber-attacks.

2. Consult user groups when designing the workplace and allocate tasks

When designing the workspace, integrators should consult different cobot user groups to provide their input when arranging/setting up the workspace, as well as developing tasks for the cobot. Operators and user groups who will directly interact with the cobot system should actively provide feedback regarding workspace arrangement and setup.

By including the staff in the planning phase, managers can minimise both physical and psychological risks through the two following elements:

- **Human-friendly workplace arrangement**: distributing tasks adequately reduces the risk of physical stress and musculoskeletal injuries.
- **Human-friendly work distribution**: arranging the workspace to allow enough distance/space between humans and cobots can reduce the risk of collisions and distress.

3. Conduct a risk assessment

According to the standard ISO/TS 15066:2016, integrators are expected to conduct a risk assessment for the collaborative operation. “Work Health and Safety Cobot Risk Assessment” provides further detail in regards to how risk assessments should be conducted in the context of collaborative operations.

4. Choose a safe location for the cobot system and ensure changes to the workspace do not generate new risks elsewhere

When planning the workspace, integrators should position the cobot system in a safe location that minimises all potential risks (see table in Appendix). If changes to the existing workspace occur, they should ensure that new risks are not generated elsewhere.

In some cases, the workspace may be dynamic, as cobots may be placed upon devices or vehicles that enable operators to easily move it around, such as trolleys. Cobots could also be placed upon autonomous mobile robots (AMRs) or automated guided vehicles (AGVs). During the risk assessment in these scenarios, integrators should ensure that safety is guaranteed in all possible locations, and eventually set virtual boundaries for the cobot system.

5. Establish clear and intuitive communication channels within the system and around the workplace

Clear communication should be established within the cobot system to allow users to understand cobot intentions and communicate commands in an intuitive manner, as expertise levels may vary between user groups (e.g. visitors would not be as familiar as operators).

Similarly, clear safety signage should be established around the workspace, and this should also be designed in an intuitive and clear manner to be easily interpreted by all user groups including non-operator users.

6. Simulate the tasks within the workspace

To minimise errors during the installation stage, simulation software can be used to visualise how the cobot will interact in the workspace and with the intended task application. This can help catch mistakes earlier in the process.

COBOT USERS
Managers and Administrative Staff

1. Include staff into decisions about how to best integrate the cobot in existing workflows and design the workplace

Staff should be included and actively consulted on how best to integrate the cobot into existing workflows, as they often have detailed knowledge about processes. This allows for safety aspects that users directly involved in the workflows could only highlight and ensures a more human-friendly workplace arrangement and distribution of tasks.

2. Engage staff through appropriate training policies for both building knowledge and skills and improving acceptance

Staff should also be engaged through appropriate training policies. In this context, training should not only be aimed to building the required knowledge and skills to operate the cobot system, but also to developing and accepting culture. The purpose of the latter is to clarify how the cobot will change workers' roles and address potential concerns about losing jobs due to cobots potentially replacing their roles. Operators and user groups who will directly interact with the cobot system should be allowed to actively provide feedback regarding workspace arrangements and setups.

3. Select appropriate cobots and end effectors, and integrate them in a safe way

Managers and integrators share the responsibility to choose the right system for the right application (see the document, 'What is a collaborative application'). Thus, they should consider the difference between the incorporated safety features of industrial and cobot specific robot systems when choosing equipment. Overall, managers should ensure that the physiological and physical stress of the cobot user is less than when working without the cobot system. This represents the most important safety indicator when planning the workplace.

Safety precautions should be taken with the cobot, end effectors, and the way in which they are integrated. The cobot should include appropriate safety modes as specified by the standards. At the same time, they should have a non-threatening appearance to improve the sense of comfort within user groups.

End effectors represent a non-negligible hazard in a cobot system and specific safety assessment are necessary for all components, as manufacturers assure the safety of a cobot as a part-machine. In this regard, the system should be personalised only to the extent to which users' safety is not further compromised.

4. Establish clear and intuitive communication channels within the system and around the workplace

Clear communication should be established within the cobot system to allow users to understand cobot intentions and communicate commands in an intuitive manner, as expertise levels may vary between user groups (e.g. visitors would not be as familiar as operators).

Similarly, clear safety signage should be established around the workspace and this should also be designed in an intuitive and clear manner to be easily interpreted by all user groups, including non-operator users.

Installation & Commissioning

Table 7 provides an overview of key tasks of this cobot lifecycle phase and relevant stakeholder roles and responsibilities.

Table 7: Responsibilities in the installation and commissioning phase

Task	Manufacturers		Distributors and suppliers	Integrators	Cobot users			
	Cobot manufacturers	Manufacturers of third-party equipment			Operators	Beneficiary users	Co-workers and visitors	Managers and administrative staff
Provide accessible documentation and or support when requested by users and integrators	R	R	A	C	C			A
Consult operators during cobot installation				R	C	C		A
Address workspace-specific risks and set safety boundaries				R	C	C		R
Use various testing procedures to address hazards and account for all aspects including the psychological and ethical impact of cobots				R	C	C		I
Include multiple fail-safe safety measures to mitigate risks whenever part of the equipment cannot naturally revert to a safe condition in case of malfunction or breakdown				R				A
Educate company and operators on best practices in cybersecurity			R	R	I			I
Ensure the cobot system includes intuitive communication channels				R	C			A
Understand how to practice safe human-cobot collaboration and the potential implications of using a cobot in a non-collaborative manner			R	R	A			R
Measure the impact of not only physical factors but also psychological ones				R	C	C		R
Ensure that unauthorised persons cannot interact with the system.				R	I			R

MANUFACTURERS

'Manufacturers' refers to manufacturers and manufacturers of third-party equipment and safety peripherals.

1. Provide accessible documentation and/or support when requested by users and integrators

In the product development phase, manufacturers must produce easy-to-understand technical and training documentation. The documentation must also provide details regarding the installation and transportation requirements, such as required number of people, tools, and process steps. Whenever documentation is found to be not accessible enough or not easily interpretable, manufacturers should be available to support users and integrators in the installation of cobots or other equipment.

INTEGRATORS

2. Consult operators during cobot installation

To support worker agency and ergonomics, when possible, integrators should allow operators to provide their input during the process of arranging and setting up the workspace for the cobot. Integrators should also communicate any changes that need to be made to the workflow operators are assigned to. Operators should be actively encouraged to actively provide feedback.

3. Address workspace-specific risks and set safety boundaries

Assess how the workspace may impact upon the safety of the intended task. These hazards can be addressed by configuring the cobot to operate within strict boundaries, clearly demarcating operational cells and stop mechanisms, and installing additional safety equipment to mitigate hazards. Integrators should program 'play-pause-stop' behaviours that allow the operator to safely pause tasks whenever they leave the workspace and stop the cobot in case of a hazard.

In some cases, the workspace may be dynamic, as cobots may be placed upon devices or vehicles that enable operators to easily move it around, such as trolleys. Or the workplace may install cobots upon autonomous mobile robots (AMRs) or automated guided vehicles (AGVs). In these scenarios, integrators should program the cobot to ensure it operates within the boundaries of the vehicle itself and ensure that the base on which it is installed is considered safe.

4. Use various testing procedures to address hazards and account for all aspects including the psychological and ethical impact of cobots

Use various testing protocols to identify the risks generated by the cobot itself, as well as additional equipment, tasks, and overall workspace. For this purpose, integrators should use various methods, including physical testing and simulation (refer to Section 4.2 on Safe Human-Cobot Interaction Guide). This allows integrators to identify not only all of the possible physical hazards, but also to address psychological and ethical concerns that may emerge from operating the cobot system (see Introduction document, Table 3). It is particularly important that integrators test critical elements that may create physical hazards, including pinch points, operation speeds, and cobot path planning. Physical testing of task applications allows them to identify potential hazards prior to operation, including psychological and ethical ones. The simulation of the workspace and workflow prior to utilisation allows integrators to anticipate potential physical hazards emerging from operations.

To further investigate psychological and ethical risks, integrators and managers should consult with the user groups that will directly interact with the cobot system through various methods (e.g. surveys, workshops), and allow them to provide active feedback at all stages. Finally, once the cobot system is installed and the settings are defined, integrators should ensure that users who interact directly with the cobot system follow the testing protocols used during installation.

5. Include multiple fail-safe safety measures to mitigate risks whenever part of the equipment cannot naturally revert to a safe condition in case of malfunction or breakdown

Whenever equipment cannot revert to a safe condition in the event of a breakdown or malfunction (i.e. it is not fail-safe), integrators should include additional safety measures that aim to ensure safety in case of system failures. Procedural and architectural redundancy is key for the overall safe system structure. This can be achieved by establishing a dual-channel system, in which two unidentical components complement the safety system. As a result, redundancy provides not only a single solution, but also multiple ones to address the risks identified in the risk assessment.

6. Include emergency stop mechanisms for all parts of the cobot system

All parts of the cobot system (i.e. the cobot system itself and end effectors) should include emergency stop mechanisms. For end effectors, integrators should ensure that the product complies with the larger cobot systems emergency stop mechanisms. In case stop mechanisms can be moved, integrators should clearly demarcate the workspace area where these can be placed and ensure that they are visible.

7. Educate company and operators on best practice in cybersecurity

Integrators should educate managers and operators about the consequences of potential cyber-attacks. They should indicate potential vulnerabilities that might expose the system to attacks or data leaks. Accordingly, integrators should also recommend cybersecurity best practices.

8. Ensure the cobot system includes intuitive communication channels

Integrators should ensure that any additional communication channel for the intuitive programming of the cobot is safely integrated into the system, as cobot users will rely on it to interact with the cobot and feel comfortable in the workspace.

9. Ensure that unauthorised persons cannot interact with the system

Integrators should collaborate with managers and administrative staff to identify the authorised personnel within the company and allow access to the workspace only to these employees. This allows them to establish different levels of access and allocate access credentials accordingly (e.g. ID and password).

COBOT USERS
Managers and Administrative Staff

1. Understand how to practice safe human-cobot collaboration and the potential implications of using a cobot in a non-collaborative manner

Managers should ensure to choose the right system for the right application throughout all phases. Purchasing a cobot does not necessarily mean that it will be used for collaborative applications. Managers should have a clear understanding of the characteristics of human-cobot collaboration and avoid using the cobot for any different purpose. As cobot systems are comprised of multiple elements (i.e. cobot, end effectors, and additional equipment), managers should also ensure that all of the elements have been integrated safely. Although each element is proven to be safe individually, it does not guarantee that the overall system will be safe.

2. Measure the impact of not only physical factors but also psychological ones

Managers should ensure that appropriate testing is conducted prior to operation (refer to Section 4.2 on Safe Human-Cobot Interaction Guide). Testing procedures, such as physical testing and simulation, allow integrators and managers to measure and assess the impact of not only physical hazards, but also psychological and ethical ones.

To minimise physical risks, managers should ensure that integrators choose appropriate settings and pay particular attention to elements including pinch points, operation speeds, and cobot path planning. To assess psychological and ethical risks, it is particularly effective to use methods such as surveys or consulting with user groups that will directly interact with the cobot. Users that interact with the cobot system directly should be allowed to actively provide feedback about various aspects, such as the ease of use and the level of comfort.

3. Ensure sufficient training for operators before they start interacting with it

Managers should establish appropriate training procedures before operators start interacting with it. They should allow sufficient time for operators to familiarise themselves with the system and its safety features and limitations before proceeding to the task at hand. Training should both cover technical aspects and address the psychological and ethical impact of cobot adoption. Ensuring that operators and beneficiary users understand the purpose of the cobot system, its capabilities, and safety features may increase a sense of comfort and reduce potential mental strain. Clarifying the roles and the changes brought about by the introduction of the cobot reduces the ethical concerns related to the fear for job loss.

4. Ensure that unauthorised persons cannot interact with the system

Managers should collaborate with integrators, identify the authorised personnel within the company, and allow access to the to the workspace only to these employees.

Use Phase and Operation

Table 8 provides an overview of key tasks of this cobot lifecycle phase and relevant stakeholder roles and responsibilities.

Table 8: Responsibilities in the use and operation phase

Task	Manufacturers		Distributors and suppliers	Integrators	Cobot users			
	Cobot manufacturers	Manufacturers of third-party equipment			Operators	Beneficiary users	Co-workers and visitors	Managers and administrative staff
Provide user-friendly troubleshooting documentation	R	R	R	C	C			A
Notify users when the system needs to be updated or reconfigured	R	R		I	I			I
Allow the use of cobot only within the recommended settings				R	A	I	I	R
Follow the safety recommendations provided by manufacturers and integrators					A	I	I	R
Monitor workspace for co-workers and visitors that may be unaware of cobot and pause tasks if necessary					R		I	
Secure the system after each operation to prevent use by unauthorised persons.					R	I	I	
Troubleshoot in a safe manner and report any observed issues or concerns to administrative staff	I	I	I		R			C
Comply with the safety protocols and understand how to locate and initiate emergency stops and comply with the safety protocols						R	R	
Report any observed issues or concerns to administrative staff					R	R	R	
Encourage and support staff					C			R
Measure the impact of cobot the system					C	C		R
Monitor how the cobot system is operated					C	C		R

MANUFACTURERS

1. Provide user-friendly troubleshooting documentation

Manufacturers of cobots and other equipment should provide accessible and user-friendly troubleshooting documentation to assist cobot users and integrators in fixing potential issues that may occur during operations.

2. Notify users when the system needs to be updated or recond

As the cobot system comprises various hardware and software components, some parts may require automatic updates or manual reconfigurations. Manufacturers, and in particular cobot manufacturers, should advise of any automatic updates or potential functions that may require reconfiguration.

DISTRIBUTORS & SUPPLIERS

1. Provide user-friendly troubleshooting documentation

Distributors should provide accessible and user-friendly troubleshooting documentation to cobot users and integrators to assist them in fixing potential issues that may occur during operations.

INTEGRATORS

1. Allow the use of cobot only within the recommended settings

After installing the cobot system, integrators should ensure that the system is allowed to operate only within the recommended settings (e.g. speed, load capacity).

COBOT USERS

Operators

1. Follow the safety recommendations provided by manufacturers and integrators

Operators should conduct their tasks as instructed in their training. They should follow the recommendations provided by manufacturers and integrators. In some cases, these might be summarised into fact sheets that are located within the workspace, so they can be available when operating and maintaining the cobot system.

2. Use the cobot only within the recommended settings

Operators should use the cobot only within the recommended settings and should not conduct tasks in any other way (e.g. increasing the speed limits or payload).

3. Monitor workspace for co-workers and visitors who may be unaware of cobot and pause tasks if necessary

As trained personnel with technical expertise, operators should monitor the workspace and prevent untrained personnel or visitor from accessing it. In case too many personnel are in the workspace, operators should pause their tasks until it is safe to proceed.

4. Secure the system after each operation to prevent use by unauthorised persons

After operating the system, operators should follow all security measures to prevent its use by unauthorised persons.

5. Troubleshoot in a safe manner and report any observed issues or concerns to administrative staff

Troubleshooting needs to be conducted by the responsible operator in a safe manner. Operators should cease operation before starting any troubleshooting. If issues persist or operators have any further concerns, they should report to the administrative staff who will contact the integrators and manufacturers.

Passive Users, Co-workers, and Visitors

1. Comply with the safety protocols and understand how to locate and initiate emergency stops and comply with the safety protocols.

Passive users, co-workers, and visitors should comply with the safety protocols all the time (e.g. do not enter demarked areas). It is particularly important that even if these users do not interact directly with the cobot system, they have a clear understanding of how to locate and initiate emergency stops.

2. Comply with operator instructions when cobot is in operation

As an operator is responsible for the cobot system, any passive user, co-worker, or visitor should follow their instructions whenever they are in the proximity, particularly if they enter the cobot workspace.

3. Report any observed issues or concerns to administrative staff

It is the responsibility of everyone to report any safety issues or concern to the administrative staff.

Managers and Administrative Staff

1. Encourage and support staff

Managers should build an accepting culture throughout all phases. After the installation of the cobot system, users should be allowed enough time to familiarise themselves with the system, as well as its safety features and limitations. Consider that the time needed may vary among users. As users become familiar with the cobot system, managers should also support them to optimise tasks to their preferences and use their specialised knowledge. Finally, managers should encourage user groups to engage in specialised training that can both improve safety and optimise operations.

2. Measure the impact of cobot the system

In order to adopt a wholistic approach towards safety, it is necessary to measure the impact of not only physical factors, but also psychological and ethical ones. This can be done through a combination of quantitative and qualitative methodologies (e.g. surveys).

3. Monitor how the cobot system is operated

When the cobot system is operational, managers should monitor operators to ensure that the cobot is used only by authorised staff and within the recommended settings. Additionally, managers should monitor for potential negligence and/or sabotage by operators and make them accountable for their actions.

Maintenance and Adjustments

Table 9 provides an overview of key tasks of this cobot lifecycle phase and relevant stakeholder roles and responsibilities.

Table 9: Resposnabilities in the maintenance and adjustments phase

Task	Manufacturers		Distributors and suppliers	Integrators	Cobot users			
	Cobot manufacturers	Manufacturers of third-party equipment			Operators	Beneficiary users	Co-workers and visitors	Managers and administrative staff
Advise for changes with software update	R	R	I	I	I			I
Sell and market as cobots and other equipment as part-machine	C	C	R					I
Maintain the system, both hardware and software, and their relative updates					R			R
Follow testing protocols whenever any system change occurs								
Ensure the software system gets updated correctly and conduct tests prior to operation if the system is affected by substantials changes					I			R
Conduct a risk assessment and testing procedures whenever a change to the workspace occurs				R	C	C		R
Conduct routine risk assessments					I	I	I	R
Establish routine cybersecurity checks					I	I	I	R
Maintain consistent dialogue with staff on their experience working with cobots and address concerns					C	C	C	R

MANUFACTURERS

'Manufacturers' refers to manufacturers and manufacturers of third-party equipment and safety peripherals.

1. Advise for changes with software update

Cobot systems are comprised of both hardware and software parts. Cobot manufacturers and manufacturers of other parts or equipment should advise about changes brought in by software updates, as these may affect the way operators and other users interact with the system.

INTEGRATORS

1. Conduct a risk assessment and testing procedures whenever a change to the workspace occurs

Throughout the lifecycle of a cobot system, different tasks or additional tools and equipment may be added to the workspace at any time. In cases where integrators are within the company, or they are still working for the company, then they are responsible for conducting risk assessments whenever a change is made to the cobot system, its functionalities, or the workspace.

DISTRIBUTORS & SUPPLIERS

1. Sell and market as cobots and other equipment as part-machine

After a cobot system is installed, companies may consider adjustments that require additional equipment or cobots. Distributors and suppliers should ensure that customers understand that cobots and related equipment are marketed and sold as part-machines. Accordingly, they should clarify which components are assured to be safe and which safety requirements should be addressed for the cobot system to be considered complete and safe.

COBOT USERS

Operators

1. Maintain the system, both hardware and software, and their relative updates

Operators should conduct appropriate maintenance to ensure the system and its hardware and software components are up to date.

2. Follow testing protocols whenever a system change occurs

Operators should follow testing protocols before the cobot system is used with any new equipment, task, workspace, or passive users.

Managers and Administrative Staff

1. Ensure the software system gets updated correctly and conduct tests prior to operation if the system is affected by substantials changes

Whenever manufacturers release new software updates, managers should update the cobot system accordingly and ensure they have a complete understanding of potential changes in the system functions. If a software update requires a cobot or supporting system to be reconfigured, then managers are responsible for conducting or overseeing testing before normal operations can resume.

2. Conduct a risk assessment and testing procedures whenever a change to the workspace occurs

Throughout the lifecycle of a cobot system, different tasks or additional tools and equipment may be added to the workspace at any time. Managers should ensure that a risk assessment and appropriate testing procedures are conducted prior to the installation of any new component or change to activities within the workspace. If integrators are within the company, or still working for the company, managers should ensure that they conduct a risk assessment whenever a change occurs.

3. Conduct routine risk assessments

In addition to the initial risk assessment, managers should ensure that routine risk assessments are conducted to identify new potential risks and mitigate them appropriately.

4. Establish routine cybersecurity checks

As cybersecurity risks may evolve throughout the cobot lifecycle, managers should ensure that system integrators conduct routine checks to identify potential weaknesses that may expose the system.

5. Establish maintenance policies to prevent safety systems failure

Managers are responsible for establishing preventive maintenance policies that reduce the risk of system failures and potential hazardous consequences. Maintenance practices should be continuously conducted throughout the operational lifecycle of the cobot system.

6. Maintain consistent dialogue with staff on their experience working with cobots and address concerns

Managers should allow users that directly interact with the cobot system to openly share their experiences and concerns at any time. This allows users to increase their safety and comfort when working with cobots, and also allows for potential areas of improvement to be identified. All future actions should include users' feedback.

Action: Refer to the 'Cobot Harms and Hazards' flyer to get an overview of physical, psychological, and ethical harms and hazards of cobots.