Guidelines for Safe Collaborative Robot Design and Implementation

Guidance on Safe Human-Cobot Interaction

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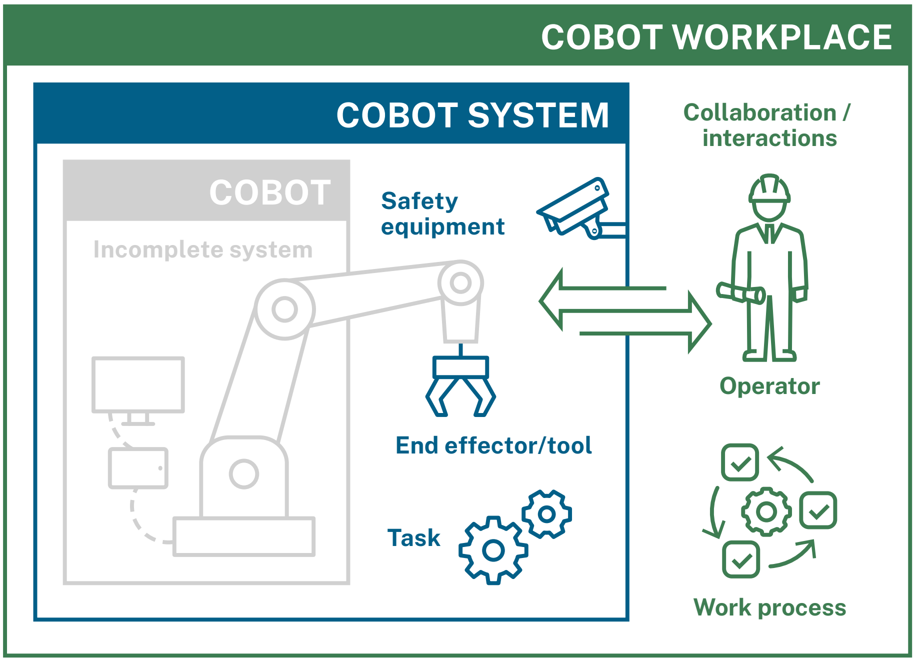
Guidance on Safe Human-Cobot Interaction

Document purpose

This document explains the different interaction modes between humans and cobots, the minimum safety requirements for each mode, and the factors that can impact the safety of these interaction modes. It also provides guidance on how to safely program interactive tasks.

How to use this document

- As an introduction to purchasing and using cobots.
- To establish safe work tasks for humans and machine.
- For training purposes and communication of risks to upper-level management.



Relevant cobot lifecycle phases

Product Development & Manufacturing	Cobot Workplace Planning	Installation & Commissioning	Use Phase & Operation	Maintenance & Adjustments
	Understand difference between cobot and other types of robot. Planning for a cobot workplace.	Provide guidance on safe human cobot interaction and programming practices.	Provide guidance on safe human cobot interactions and programming practices.	Provide guidance on safe human cobot interactions and programming practices.

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		ASSESSMENT OF EXISTING WORKPLACE	
✔ Guidance on Safe Human-Cobot Interaction	Designing a Safe Cobot Workplace	Cobot Workplace Safety Checklist	Cobot Work Health and Safety Risk Assessment

Cobot Safety Flyers

Contents

How to use this document

This guideline document provides a comprehensive explanation of what human-cobot interaction means and how it should be designed to be safe. In this document, readers can:

Learn more about:

- Human-cobot interaction
- The benefits and safety requirements for different interaction modes
- The differences between a cobot and other robots
- How to safely program a cobot for interactive tasks
- How to safely test a cobot for interactive tasks

Refer to this information to:

- Train operators and integrators on safe human-cobot interaction practices
- Communicate cobot-specific hazards
- Produce safety resources for relevant stakeholders

> **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.

Planning for safe human-cobot interaction

When purchasing, integrating, or changing the use of an existing cobot in your workplace, it is important to practice safe human-robot interaction. Understanding the task requirements, the workspace, and the cobot's limitations will help when planning to use a cobot in a safe manner.

It can be difficult to understand the differences between cobots and other types of robots. However, for safety purposes, it is more important to understand how to assess whether your workplace can adopt human-cobot interactive tasks. Therefore, in these guidelines, what is considered a 'safe cobot' goes beyond a simple machine that is simply purchased and set up. The guidelines therefore emphasise the importance of considering the entire cobot workplace, including workplace practices, processes, and human-cobot interaction.

This scope allows the guidelines to be relevant to any robot applications that operate within one of the three modes of human-robot interaction highlighted in Figure 1, regardless of whether you have purchased a machine marketed as a cobot or are using an existing robot in your workplace for interactive tasks.

> **Note:** Robots that are marketed as 'cobots' can still be used in ways that are dangerous for human-robot interaction. Therefore, the entire socio-technical cobot workplace needs to be considered.

What is the difference between human-robot interaction and human-cobot interaction?

Human-robot interaction is an umbrella term that refers to the process of humans and robots safely working together to achieve shared goals. Human-cobot interaction is a specific type of human-robot interaction where humans and robots can safely work on tasks in a shared workspace.

The following refers to different modes of interaction that can occur **during operation**.

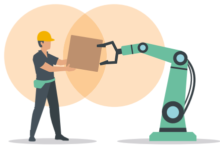
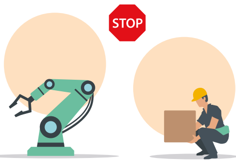
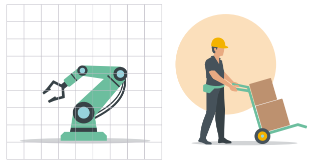
Human-robot interaction can be distinguished into three interactive modes and one non-interactive mode.

1. **Collaboration:** Cobot and human work hand-in-hand at the same time in a shared workspace to complete a task, similar to how two humans would work together.
2. **Cooperation:** Cobot and human work on the same task in a shared workspace, but not at the same time. Usually one needs to complete a step before the other one can work.
3. **Coexistence:** Cobot and human work in a shared space but on different aspects of a task; normally the cobot stops for the hand-over of work objects between cobot and human.
4. **Cell:** This non-interactive level is typical for traditional industrial robots. This is when a machine works in a physically enclosed space with no direct human interaction during operation.

Each of these modes has unique benefits and safety requirements that need to be addressed. As outlined in Figure 1, the collaboration and cooperation interaction modes are considered human-cobot interaction modes as the machine and human work in a shared working space. These guidelines will use the more general term of 'human-robot interaction', to provide guidance on a wider array of use cases for cobots.

Understanding the differences between these modes can help clarify what type of cobot/robot would be appropriate and safest for your intended task application.

Figure 1: Typology of general interaction modes during operation. (Kopp et al., 2020)

	COBOTS Human-robot interaction			**ROBOT** No human-robot interaction occurs
	Increasing level of interaction			
	Human Cobot Interaction			
Interaction mode	**Collaboration**	**Cooperation**	**Coexistence**	**Cell**
Illustration				
Intended Interaction of human and cobot	Human and cobot work together on the same task at the same time (simultaneous)	Human and cobot work together on task sequentially (step-by-step)	Human and cobot work together on task sequentially (step-by-step)	Human and cobot work together on task sequentially (step-by-step)
Workspace	Shared working space	Shared working space	Separated working space	Separated working space
Physical contact	Required	Possible, not necessary	Possible, but should not occur	Hazardous
Minimum safety requirements	Speed and separation monitoring, power and force limiting, and hand-guided control	Speed and separation monitoring and power & force limiting	Safety-rated monitored stops	Physical barrier
Examples of tasks	Hand-guided assembling/painting/ etc.	Inspection and tuning processes (e.g. welding applications)	Shared assembling, shared handling, testing, benching, cleaning, and service	Loading/unloading, testing, benching, cleaning, service, automatic stacking/de-stacking, guided assembling, and guiding filling/unfilling

What is a task application?

An interactive task application is the assigned activity that a cobot has been programmed to perform. It is important to consider how the cobot will directly interact with humans in a specific workplace and how it will be influenced by and affect the wider organisation. This means that different people may have different interactions with the cobot while programming the task application.

The process of programming a cobot task application is different from operating the machine. There are different safety procedures and practices that need to be considered when writing a program for a cobot. These different procedures can mean that programming and operation are not always completed by the same person. When this happens, there can be a gap between the experience of the integrator programming the cobot and the operator using the cobot itself (for more information, refer to Table 1 in “Designing a Safe Cobot Workplace”).

Integrators can sometimes overlook the factors that make a task unsafe for human-robot interaction and miss observable risks and hazards. That is why it is important to conduct rigorous tests, consultations with technical staff and operators, and training for operators. Doing so will ensure that the task application safely:

- interacts with operators and/or other personnel;
- operates in the cobot workspace without creating hazards and obstructions;
- integrates into other work processes in your workplace (e.g. the cobot placing an object onto a conveyer belt); and
- completes the intended task correctly.

Understanding cobot workspaces

A cobot **workspace** is the defined physical space in which a cobot is configured to operate within and potentially physically interact with humans. Traditionally, this can also be called a **work cell**. A cobot workspace is different from your **workplace**, cobot system, human operators, and other work processes. These are instead the general areas where humans and/or machines work together (e.g. your office, factory floor, warehouse, workshop, or studio).

Defining the cobot workspace can be done using physical barriers and/or by virtually programming boundaries that limit the cobot from moving outside of the defined space. Defining a workspace should also consider the **workpiece** that the cobot and/or operator is working with. A workpiece is the object or material that the cobot and human are working on, for example if a cobot is assigned to complete a welding task, the sheet of metal would be considered the workpiece.

Physical barriers can range in complexity and security. Some workplaces will place a robot working in 'non-interactive' or 'cell-mode' in a locked room or metal cage. To enter the workspace, a person must have authorised access to unlock and enter the workspace. These workspaces can also be configured so that the door cannot be opened until the robot is turned off. This offers an additional layer of safety to prevent unwanted interactions between an automated robot and people. These barriers can also be used to prevent unauthorised personnel from entering the cobot workspace.

> ⚠ **Note:** What may be safe for an operator or integrator can still be hazardous for visitors and staff that have not been trained in cobot safety.
>
> In such cases, some workplaces will physically demarcate the workspace using less obtrusive barriers such as handrails and tape to prevent unexpected visitors and other staff from accidentally entering the workspace.

Who can interact with cobots?

While it is possible to let a cobot interact with anyone, it is advisable to limit cobot interaction to specific people who understand how to safely work alongside cobots. An individual's expected level of understanding of safe work with cobots depends on their role and responsibilities. Not everyone will interact with a cobot in the same way. Below are several examples of how different stakeholders could interact with a cobot.

- The person responsible for programming the cobot may use hand-guided controls to set the task, but the task itself may place the cobot in a physical cell where no human interaction occurs.
- The operator may only be required to supervise the cobot while working on adjacent tasks simultaneously.
- A trained operator works closely with a cobot to complete a task.
- Visitors and non-cobot-trained staff are unauthorised to enter the cobot workspace. This may mean that the workplace installs physical barriers that prevent unwanted interaction.

Locking or password protecting the teach pendant, controller, computer, or the cobot workspace itself are useful methods to limit unauthorised personnel from interacting, tampering, or operating the cobot. Logging of attempts to access the cobot system can help workplaces monitor who is using the cobot.

Action: Refer to the "Designing a Safe Cobot Workplace" document to learn more about the roles and responsibilities of different stakeholders.

Human-Cobot Interaction

A higher level of interaction (e.g. collaboration instead of coexistence) may not always be the most appropriate, safe, or cost-effective solution for the intended outcome. Generally, higher levels of interaction require more complex assessment of safety measures and integration of the task into other work processes. When assigning a task, assess whether your workplace has the capacity to adopt more complex safety requirements and practices.

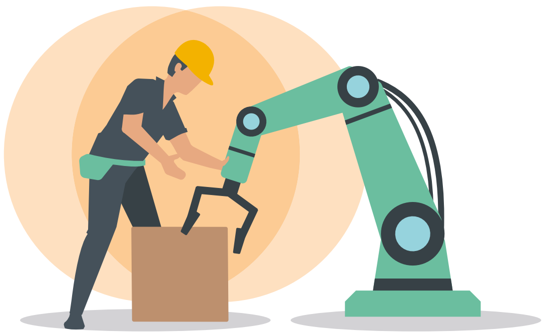
Benefits and safety requirements of each interactive level during Use Phase and Operation

The following interaction modes are fluid and different people in your organisation may have varying levels of interaction with a cobot. The benefits and safety requirements provide general guidance for the cobot during its use and operation phase.

Action: Refer to the "Four Modes of Cobot Safety" flyer to learn more about common cobot safety modes.

Collaboration

Humans and cobot work in the same unfenced space on the same task together, physical contact is required to complete the task.



Benefits

Collaboration is the highest level of interaction, which involves humans and the cobot completing the same task together with physical contact. Collaboration is useful for tasks that are difficult to completely automate but are intuitive for humans to complete.

Requirements

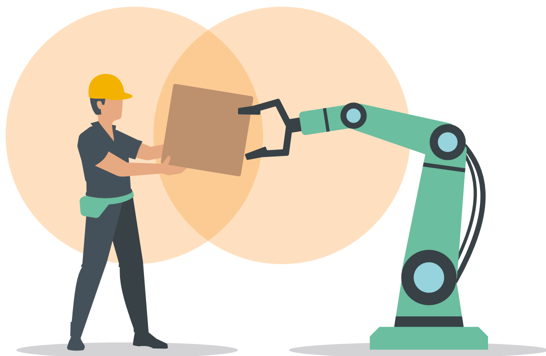
Alongside the speed and separation monitoring and power and force limiting safety requirements, operation is directed by hand-guided control. This involves the human operator physically moving the cobot arm, workpiece, and/or end effector during operation to complete the task. The cobot must adhere to safe work practices for humans, such as the 'Code of Practice for Hazardous Manual Tasks'.

Example use case of collaboration

Rehabilitation robots.

Cooperation

Cobot and operator can work in the same unfenced space on tasks that are linked together, physical contact is possible but not necessary.



Benefits

This interaction mode is useful if the machine needs to work alongside a human in a shared workspace. This enables human workers to interact with shared objects that the cobot may be also tasked to work with. Cooperation is useful for operators who need assistance to quickly work on larger workpieces.

Requirements

According to the ISO 10218-1 standard for collaborative robots, this interaction mode must ensure that the cobot system has **speed and separation monitoring** so that it can slow down when humans are detected in the work cell with the machine. The **power and force** exerted by the cobot arm and other tools must be limited. If the cobot is sharing objects with humans, it must adhere to safe work practices for humans such as the 'Code of Practice for Hazardous Manual Tasks'.

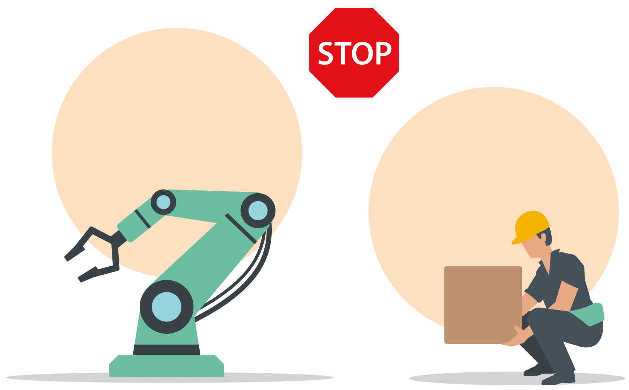
Example use case of collaboration

Shared assembling, handling, testing, or cleaning.

Co-existence

The cobot works in an unfenced space but does not physically interact with the operator.

Either cobot or human are allowed to work on a task at any given time. If one works, the other one has to stop.



Benefits

Co-existence is the lowest level of interaction. This mode enables automated work to occur without the need for physical barriers. Co-existence allows for efficient use of floor space where other types of tasks are performed. This mode enables operators to supervise automated tasks while completing other tasks.

Requirements

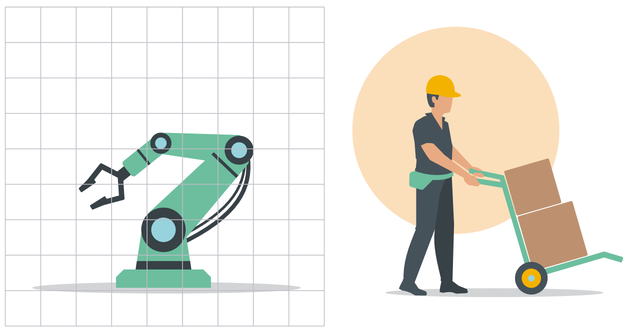
This type of interaction requires the cobot to be configured with safety-rated monitored stop mechanisms that stop the machine when a person walks into the defined work cell of the cobot. This can interrupt other work processes and delay operation. This mode is advisable in workplaces that do not have a high number of people working in a small or restricted space.

Example use case of collaboration

Supervising welding application.

Cell – Non-cobot mode

The robot and operator must not physically interact, and the robot must be fenced.



Benefits

Cell operation mode enables the machine to work at its highest speeds and payloads without risking the health and safety of operators and others in the workspace.

Requirements

Cells must be installed with fencing which makes more floor spaces unusable for other work. Irrespective of whether the robot is marketed as a 'cobot', if it is operated as a robot (e.g. through using unsafe end-effector tools), it should be placed in a cell and follow existing standards for industrial robots.

Example use case of collaboration

Automated assembly.

Factors that impact safe human-cobot interaction

Cobots can be dangerous for human-robot interaction. Purchasing a cobot does not mean that the machine is safe to use for every tool, task application, and/or workplace. Even if you have specifically purchased a machine that is marketed as a cobot, the way that you intend to use the machine dictates whether humans can safely interact with the machine.

There are **eight key factors** that may make it unsafe for a cobot to operate in an interactive mode, as follows.

These factors can be mitigated through comprehensive risk assessment processes. However, it may be safer, less complicated, and cheaper to reduce the level of interaction between the cobot and humans. This is especially the case when these factors compound upon each other and require complex safety measures to mitigate the unsafe working conditions for humans.

Action: Refer to the "Cobot Workplace Safety Checklists" and "Cobot Risk Assessment" documents for guided documentation of all hazards that may create unsafe interactions.

Table 1: 8 Factors that Impact Safe Human-Cobot Interaction

Factor	Impact on safe human-cobot interaction
1. Task Application The programmed activity that the robot/cobot has been assigned to complete.	Cobots can be tasked to complete dirty, dangerous, and repetitive work. However, if the cobot shares the same workspace as a human, ensure that the task does not place the human operator at risk of any task-specific risks and hazards.
2. Workpiece The material or object that the cobot and/or human are working on.	Debris can be a natural by-product of a task. The task application may create debris and dust that creates unsafe working conditions for humans including, but not limited to: poor ventilation, tripping and slipping hazards, fires, fine and fast-moving particles, and chemical spills. If the cobot shares the same workspace as a human, ensure that any risks and hazards that can occur due to the workpiece do not harm any humans (e.g. by providing personal protective equipment).
3. End Effector and Tools A piece of equipment that is installed to the end of a robot arm.	The tool that is attached to the cobot may make any human-cobot interaction hazardous. For example, installing a sharp open blade to a cobot will result in a hazardous working environment. This is especially important for tools that have not been specifically designed for human-cobot interaction, as these end effectors and/or tools will not have inbuilt safety systems that can detect hazards. This prevents end effectors from communicating with the rest of the cobot system during an emergency stop. Consequently, that while a cobot arm may stop moving after an emergency stop, a device such as a drill attached to the end effector will not stop. Examine what hazards are present when end effectors and/or tools interact with a task and the workpiece.
4. Movement Path The cobot arm and end effector movement trajectories that have been programmed.	Relevant to cobot arms, the path in which the arm, end effector, and workpiece move should not create risks to people working in the same workspace as the machine. Be careful to consider the head height of humans working in the workspace.
5. Operating Speed and Payload The speed of the cobot arm and end effector during operation and the weight of the object that is being carried by the machine.	Examine what hazards are present when the cobot moves around a space quickly. Consider whether the end effector and cobot arm safely hold the weight of any objects for a task. If humans share space with this type of operation, a collision into a heavy and fast-moving object will cause serious harm. Investigate what possible risks could occur if a cobot is moving quickly and holding onto a heavy object. This is especially important if the cobot is installed without physical barriers, which could otherwise intercept and protect against an object that is mistakenly thrown across the workspace.

Factor	Impact on safe human-cobot interaction
6. Workspace The space in which a cobot is configured to operate within.	Cobots are usually configured and programmed to work within the boundaries of set spaces. This prohibits the cobot from moving in areas where humans may be working. When this is not possible (e.g. installing a cobot on a mobile object), it is important to reconsider what safety measures can be used instead. If there are no appropriate measures, it may be necessary to operate the task in the cell (non-interactive) mode. In co-existence and/or cooperation interactive levels, safety equipment and sensors may need to be installed to achieve the minimum safety requirements such as safety-rated monitored stop, speed, and separation monitoring. Consider whether there is enough space to install appropriate safety equipment, such as light curtains, so there is time for the cobot to safely slow or stop operations. A cobot cell may be safe for some people, such as an operator or integrator, but unsafe for visitors and other staff who have not been appropriately trained in cobot safety. If this is the case, it is important to utilise physical barriers or signage to prevent unauthorised personnel from entering the work cell. If it is difficult to clearly demarcate the workspace, for example a thoroughfare for untrained personnel to move around, it may be hazardous for a cobot to work in that workspace.
7. Operator's Level of Expertise and Skills The person/s tasked with interacting with the machine.	Operators who have not received adequate training may be unable to safely stop and troubleshoot issues that occur during operation. They also may program a task for the cobot to complete without having an awareness of the hazards and safety requirements needed for specific interaction modes. There is a higher risk of hazard when operators lose focus. It is important that operators take regular breaks to regain focus, and limit opportunities for visitors or other staff members to distract operators while they are working.
8. Integrator's Level of Expertise and Skills The person/s responsible for personalising the cobot for the specific task and workplace.	Integrators who do not have prior experience working with cobots may not safely integrate, program, or configure a cobot to the specific standards or appropriately address the risks and hazards.

Guidance on safe programming

There are different safety procedures and practices that need to be considered when assigning a task for a cobot. This section is helpful for people that are responsible for programming a safe human-cobot interactive task application.

Depending on the model, your cobot may have the ability to run in different configurations. Generally, there are two main configurations:

- **Programming:** when someone is assigning a task application to the cobot and/or configuring the machine to the workspace. It is also known as "*teach mode*".
- **Operation:** when an operator and/or a passive user is interacting and using the cobot to complete the intended task application or outcome. It is also known as "*run mode*".

The programming configuration typically moves or 'jogs' the cobot at slower speeds to ensure that it has been programmed correctly. The task application may be programmed by using hand-guided operations to move the cobot arm to specific coordinates. Hand-guided programming is more intuitive for people and can be quicker than using the teach pendant or programming remotely.

You may use this mode when:

- Assigning the cobot its first task or a new task application;
- Configuring the cobot to a new workspace, tool, or workpiece;
- Training new staff in cobot safety;
- Training staff on the operation of the cobot for its task application; and
- Conducting maintenance or troubleshooting errors.

Outside of operation, individuals with varying roles and responsibilities in your organisation may be authorised to engage with the cobot in different interaction modes. For example, an integrator may use the collaborative interaction mode to hand-guide the cobot arm to specific coordinates to program the movement path quickly. However, during the operation phase the machine is placed in a cell with no human interaction.

When programming a cobot, it is important to understand the basics of motion planning, movement types, and the programming language for your specific machine. Even if you have prior experience programming for robots or cobots, different models can vary in how they are programmed.

Most robotic manufacturers, suppliers, and distributors provide training courses, resources, and/or documentation to assist with programming. If you are not confident in programming a cobot, especially a cobot that you will not be operating, it is best to consult with professional third-party integrators for support.

Programming and operation are not always completed by the same person. When this occurs, there can be a gap between the experience of the integrator programming the cobot and the operator using the machine itself. Integrators can sometimes overlook the factors that can make a task unsafe for human-cobot interaction and miss observable risks and hazards.

To limit this, it is important to consult with technical staff who have experience completing a specialised task (e.g. welding). If the intended operators do not have technical skills, knowledge, or experience working with cobots or a specific task, then it is important to also train operators and consult with them to understand if the task can be completed effectively and safely by a cobot.

Maintaining a human focus for human-cobot interactive tasks

Human-cobot interaction also involves humans, which means maintaining a human focus when planning for a cobot-friendly workplace is integral. If you are responsible for assigning tasks to a cobot, consider whether the task is human-friendly and considers the physical, psychological, and ethical needs of your staff.

Although cobots can work continuously without the need for rest or breaks, humans working with cobots still do. This makes it important to establish human-friendly work processes that build in breaks for operators and other staff members to maintain focus.

When assigning a task to a cobot, consult with operators and other personnel who interact with the machine to understand how best to optimise the task in order to minimise cognitively overloading them. This can help to manage the mental strain and fatigue that may occur when interacting with cobots. Alongside consulting with robot and cobot standards, it is recommended to conduct conventional workplace safety and ergonomic assessments to ensure that the task application is human-friendly.

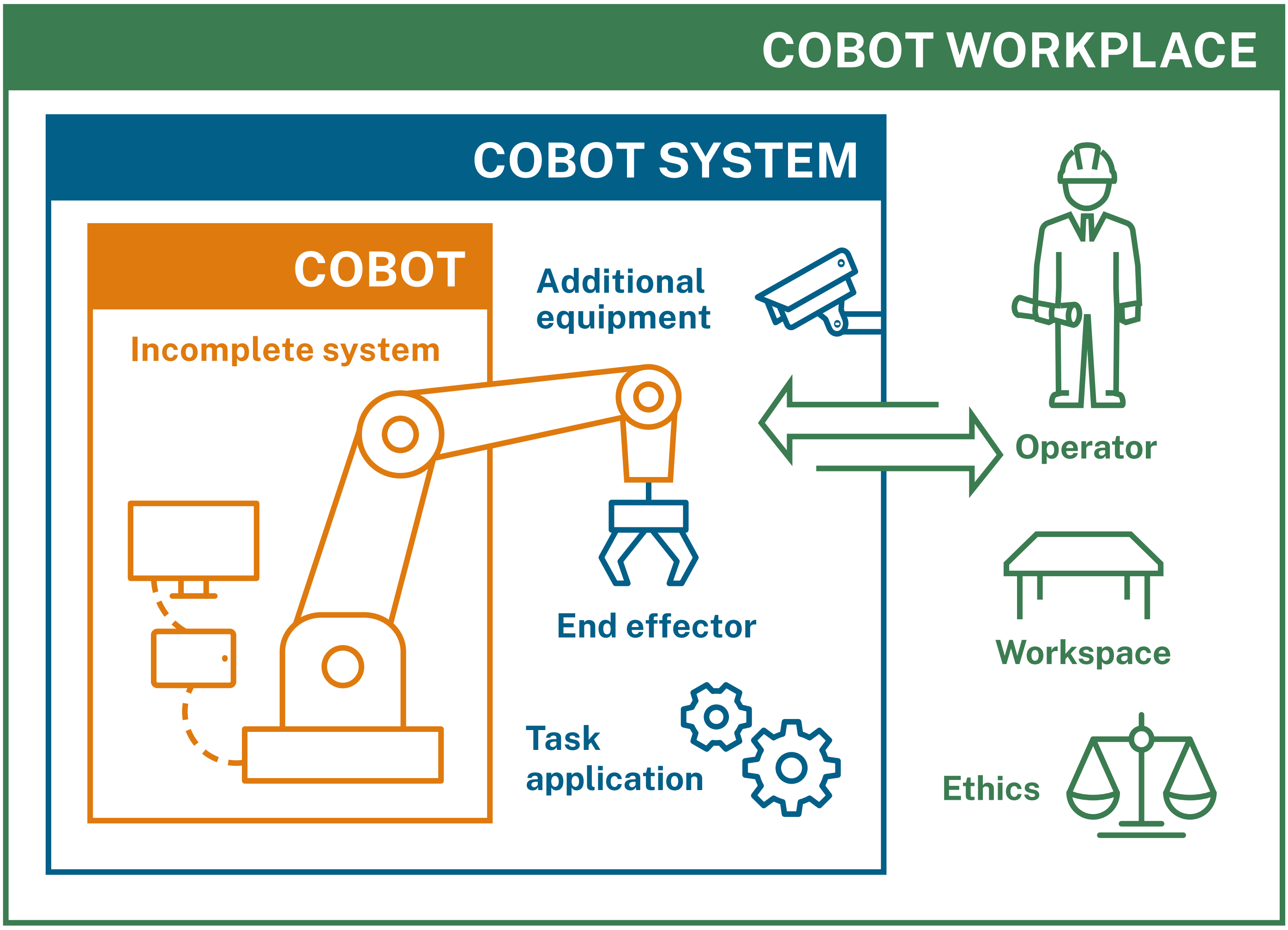
Introducing new technologies such as cobots can make staff members feel anxious about their role in the workplace. Constant consultation with your team during all phases of a cobot's lifecycle is not only helpful in minimising physical risks, but can also improve your team's acceptance of cobots and help support their agency as workers.

Guidance on testing a new program

Testing protocols can help to address the gap between programming and operating a cobot. Testing should occur before any operation, this includes the first time that a cobot is used, or if any changes have been made to the cobot workplace, cobot system, or the cobot arm itself.

Below is a general guide to comprehensively test task applications. Depending on the context of your cobot, task application, and workplace, it may not be necessary to begin at the first step. Tailor this testing protocol to your existing workplace risk assessment processes and practices.

Figure 2: A cobot, its system, and surrounding workplace



Testing Protocol:

1. Run a simulated program of the planned movement of the cobot.
2. Install the cobot in the physical workplace and ensure that the machine can be operated remotely.
3. Run the program for just the cobot arm at a slower speed than the intended operating speed, without the end effector, workpiece, or human interaction.
4. Run the program at a slower speed with the cobot arm and end effector.

5. Run the program at a slower speed with the cobot arm, end effector, and workpiece.
6. Run the program with the intended users (operator, passive users, etc.) in the workspace at a slower speed.
7. Run the program with intended users conducting their assigned task at a slower speed.
8. Run the program at normal speed with intended interaction.

During each step:

- Identify and address any hazards and include them in risk assessment documentation.
- Ensure that two people are present during the test, with each having direct access to an emergency stop.
- Consult with everyone who will be interacting with the cobot during operation to make sure that they are comfortable.