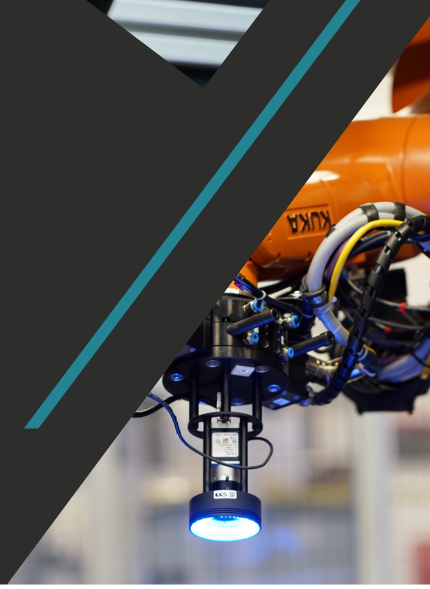

A GUIDE TO HUMAN-ROBOT COLLABORATION IN MANUFACTURING

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CONTENTS

Introduction	5
Human-Robot Collaboration	7
Definitions	7
Methods for Safe Collaboration	8
Levels of Interoperability	9
Benefits of Human-Robot Collaboration in Manufacturing	11
Common Examples of Robots in Collaborative Applications	12
Components of a Robot System	16
The Robot(s)	16
End-Effectors and Tooling	17
Fencing and Sensors	18
Positioning and Mobilising the Robot	20
Machines, Jigs, and Fixtures	21
How Staff Interact with the Robot System	21
Designing an Automated Process	22
Key Thoughts	22
Collaboration and Safety	23
Finance	24
Supplier and Integrator Selection	24
The Automation Journey	26
Case Study: CBE+	28
Key Takeaways and Further Exploration	29


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INTRODUCTION

It is no secret that the use of robotics and automation can significantly boost productivity for manufacturing companies and support with dull, dirty, and dangerous tasks. Despite this, the UK is lagging in its adoption of these technologies, standing at only 25th in the global league table for robot density per 10,000 workers as of 2023, having fallen from 24th position in 2022[1]. Given the abundance of Small or Medium Enterprises (SMEs) within the UK, one of the key issues is that many find it difficult to identify opportunities to integrate automation or are reluctant to invest due to concerns over technical risk, a lack of internal skills to handle new technologies, high initial setup costs and long payback periods. Original Equipment Manufacturers (OEMs) for automation technology have been developing ways of overcoming these challenges, with particular interest in "cobots" growing rapidly since their introduction to the market. These are robots designed with human-robot collaboration in mind, enabling new opportunities for automating manufacturing processes and enabling employees to perform more interesting, higher skilled tasks rather than those that are considered dull, dirty, or dangerous.

Reshoring manufacturing has become an ever-increasing priority for many companies within the UK following increasing levels of global supply chain disruption. In addition to this, there is an ongoing trend of product lines becoming increasingly high-mix low-volume as customer demand for greater customisation and personalisation increases. Subsequently, the popularity of robots that are easier to install and reprogram is growing, despite them typically having reduced speed and power to improve safety for nearby people.

[1] International Federation of Robotics (ifr.org)

Cobots are also referred to as "collaborative robots", but it may be more useful to consider them more specifically as:

"Robots designed to be **easily implemented** in **collaborative applications"**

"Robots designed

With rounded surfaces, reduced power and payload capacities, and sensors to detect collisions, cobots are specifically designed to minimise the risk of harm and stop moving in the event of a collision with a person – whether it is intentional or not.

easily implemented

Although marketing by cobot manufacturers initially focussed on the potential for human-robot collaboration, the resulting ease-of-use benefits have become the most significant advantage of cobots. The technology enables automation in places where it was previously infeasible and makes implementation and reimplementation far simpler. The sensor and control technologies that enable these ease-of-use benefits are being developed for larger, more powerful robots like the ones traditionally found in car factory lines locked away behind cages.

collaborative applications"

Just because cobots have built-in safety features does not mean the rest of the application is safe for human-robot collaboration. The tooling and machinery – even the workpiece itself – must be considered for safety implications before an application is suitable for collaboration. Nevertheless, it could still be worth using a cobot for a non-collaborative application to trade speed and power for ease-of-use, especially if the application would not utilise higher speeds or payload capacities. Conversely, just because a robot has not been designed for human-robot collaboration does not mean it is impossible. Adding sufficient sensors and control methods can facilitate safe collaboration with more powerful robots, though this may require a greater understanding of automation and safety, either in-house or from an external integrator.

The risks of automation adoption can be mitigated by a greater understanding of the technology, knowing how to maximise the advantages, and appreciating situations where cobots and collaboration are not the optimal solution. This guide aims to help optimise the implementation of robots in collaborative applications. The initial section explains the differences between robots and robot systems and the concept of human-robot collaboration, to alleviate common misconceptions and demystify some of the language used. Section 2 explains the importance of each part of a robot system, and how they all interact in terms of human-robot collaboration and safety. Section 3 discusses the process of implementing automation and human-robot collaboration.

HUMAN-ROBOT COLLABORATION

DEFINITIONS

Robot[2]
An automatically controlled, reprogrammable multipurpose manipulator, and its controller.

Robot System[2]
A system comprising of a robot, the end-effector, and any machinery, equipment, devices, external auxiliary axes, or sensors supporting the robot in performing its task.

End-Effector[2]
A device or tool attached to the wrist of the robot to enable it to perform its assigned task.

Human-Robot Collaboration[3]
Activity where humans and robot systems directly work together, safely, to achieve the same goal.

Robot Workspace[4]
The volume within which a robot can operate. This is limited by hardware and software constraints.

Collaborative Workspace[2]
The volume within the robot workspace within which humans and robots can safely work on tasks simultaneously.

Workpiece[4]
The object that the robot is processing, refining, or assembling into a finished product.

Cobot
A robot that has been specifically designed by the OEM for use in human-robot collaboration. They typically have:

- Rounded surfaces to reduce pinch points.
- Limited speed and payload capacities to minimise impact in the event of a collision with a human.
- Sensors to detect collisions and signal the robot to stop.

Cobot designs are becoming larger and have greater payload capacities. Meanwhile, more sensors and safety features are being integrated with powerful industrial robots that traditionally would have needed fencing to keep people out of their workspace. The boundary between "industrial robot" and "cobot" is becoming blurred.

In this booklet, "cobot" refers to robots that have been designed for collaborative applications using Power and Force Limiting, rather than referring to any robot modified for use in a collaborative application.

Robots and Robot Systems
A distinction is made here between a robot and a robot system. A robot alone cannot perform a task or manipulate objects. Once combined with other equipment to form a robot system, it can execute tasks.

Whilst a cobot may be safe by itself, the way the other parts of the system interact with people must also be assessed for safety.

[2] ISO 10218-1:2011 - Robots and robotic devices — Safety requirements for industrial robots — Part 1: Robots

[3] A conceptual framework to evaluate human-robot collaboration | The International Journal of Advanced Manufacturing Technology (springer.com)

[4] Glossary of Robotics Terms | Robotics Definitions & Examples (motoman.com)

METHODS FOR SAFE COLLABORATION

Ensuring a robot system is safe is paramount, so industrial standards define four methods that can be used to make a robot safe for use in a collaborative application, through slowing or stopping the robot before hazardous contact with a person can be made. The best method to use depends on the application and the outcome of the risk assessment.

Safety-Rated Monitored Stop

The robot undergoes a protective stop prior to a person entering the collaborative workspace. The robot is still powered but does not move so that it can automatically resume high-speed operation once the person leaves the workspace. This can be implemented with a variety of sensors such as light curtains and pressure mats.

Hand-Guiding

When in hand-guided mode, the robot remains in a safety-rated monitored stop until an operator directly controls the robot's motion. If the robot is Force and Power Limiting, then the operator can directly move the end-effector. Otherwise, they need to move a hand-held device connected to the arm, with an emergency stop and an enabling device for activating hand-guidance mode. Force sensors in the arm detect the movement by the operator and slowly moves the arm accordingly. This makes the operator feel like they are moving the payload or tooling as if in zero gravity, like an intelligent lift-assist device.

Hand-guided control can also be used to train the robot's path, either by moving the end-effector to positions and saving them as waypoints or by recording the complete path including curves. The robot can then repeat this path independently, making programming the robot far simpler and more intuitive.

Hand-Guided Training

Hand-guiding allows an operator to easily train the robot, even without programming experience. Once trained, the robot can be placed within a cage for safe operation.

Loop Technology and the MTC developed an automated annealing system where a trained operator guides the end-effector of a Fanuc CR-35iA cobot around the unique pipe shape while the annealing tool is deactivated. The robot is then placed within a cage and the annealing head is enabled, safely separating the operator from potential burns, and removing the need for the operator to wear a full-face respirator.

This process is often implemented for welding operations for similar reasons. The operator can utilise their skillset during the training progress but does not need to be highly trained in robot programming. While the robot mass produces bulk parts, the operators can be better utilised on producing bespoke products.

Speed and Separation Monitoring (SSM)

A fast-moving robot takes time to slow to a complete stop. Using cameras or laser area scanners, SSM monitors the separation between the robot and nearby person and slows the robot's speed as that separation decreases. The robot stops moving once the person comes close enough that they can reach out and touch the robot. The separation distance is calculated from the expected speed of the operator, the speed of the robot, and the expected response time of the system. The separation distance is generally larger than strictly necessary to account for sensor inaccuracies (both in terms of measurement and detection of small extremities like fingers), unpredictability of human movement speed, and system reaction speeds.

Power and Force Limiting (PFL)[2]

To minimise risk of sharing the robot's workspace while it continues operation, PFL robots are inherently designed to have limited weight and payload capacity and safety-rated control of speed. Upon contact with a person, the power and force applied are low enough to be safer for transient (non-clamping) impacts. Additionally, power and force feedback sensors within the joints of the robot stop the robot when it detects contact with a person, reducing force through deceleration and minimising the risk of quasi-static (clamping) impact. PFL facilitates the highest levels of interoperability at the expense of speed and payload capacity.

LEVELS OF INTEROPERABILITY

Interoperability refers to the degree to which a person interacts with a robot within a robot cell. These terms can differ across industry as they describe broad categories - specific examples may not fit within one category exactly.
Whereas the benefits of automation can increase as the level of automation increases, the benefits of collaboration do not increase as the level of collaboration increases. In fact, the more collaboration the process has, the more safety precautions are needed which could also mean slowing the system down. Identifying the correct level of collaboration for the manufacturing process can help to minimise costs and reduce inefficiencies.

INCREASING LEVEL OF COLLABORATION

INCREASING NEED FOR INTRINSIC SAFETY FEATURES

CELL

The robot cell is totally isolated from people by fencing, physically preventing access during operation. All systems in the cell should be depowered when a person enters the workspace, for example to perform maintenance.

COEXISTENCE

The robot is not physically isolated by a cage, but there is no shared workspace. SSM can use vision systems, light gates, or pressure mats to slow the robot based on proximity of people so the robot can be stopped before its workspace is entered. This can avoid the time consuming and costly need to depower the robot system, however unrelated nearby foot traffic could make the robot less efficient if the system is not set up thoughtfully.

SEQUENTIAL COLLABORATION

There is an overlap in the workspace of the robot and a person, but they are not operating within the shared workspace simultaneously. When a person enters the shared workspace, a safety-rated monitored stop is initiated to prevent the robot from moving. The person can then safely perform their task on the workpiece. The workpiece could be on a worktop or in a jig or fixture, or it could be held in place by the robot - powered to support the weight of the workpiece in the required position, but unable to move.

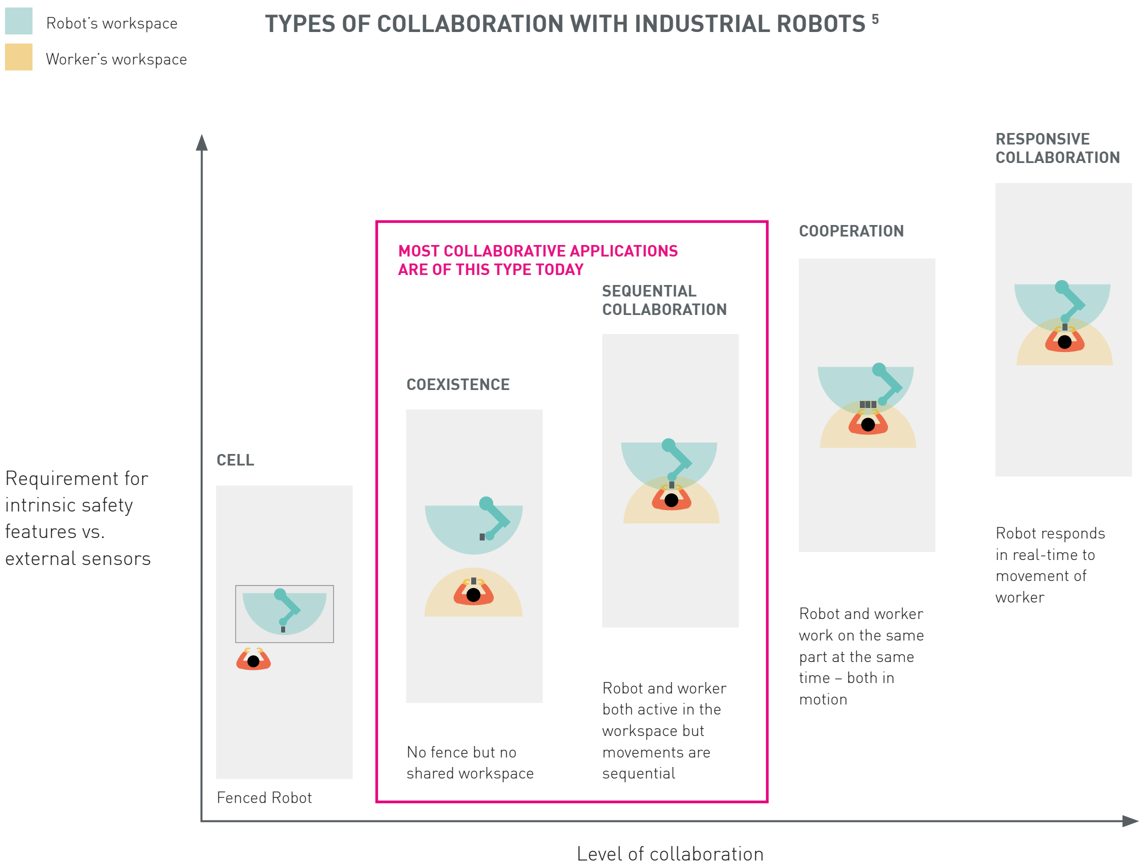
COOPERATION

The robot and person are within the collaborative workspace simultaneously, working on the same workpiece at the same time. They could be performing different tasks with the robot operating under PFL control, or they could be performing the same task such as manipulating a heavy workpiece through hand-guided control. Cobots have force sensors and control software built in, which are required for PFL and hand-guided control.

RESPONSIVE COLLABORATION

The robot responds to the movements of the person in real-time to collaborate on a task and/or avoid contact while operating within the collaborative workspace. Although this may be what is imagined when thinking of "human-robot collaboration", this capability is still in research stages and is not yet found in industry as robot motion is not precise or consistent enough for manufacturing.

TYPES OF COLLABORATION WITH INDUSTRIAL ROBOTS [5]



BENEFITS OF HUMAN-ROBOT COLLABORATION IN MANUFACTURING

Traditionally, robots and people have been physically separated from each other and performing separate tasks. With advancements in safety technologies, humans can now collaborate with robots on the same workpiece or even same task, at the same time. This can bring a variety of benefits, including:

Reduce Space Requirements

Designing a robot system with PFL and/or SSM can eliminate the need for fencing, reducing the amount of valuable space required and enabling automation to be implemented where it previously could not.

Program with Ease

Intuitive icon-based programming and hand-guided training improve the ease of use of robots, reducing the need for high-level programming skills. Expert process operators can quickly learn

[5] IFR (classification), adapted and modified from Bauer et al. (2016).

to program the robots and apply their professional knowledge of the application to the robot program.

Improve Health and Safety

Repetitive tasks are unfulfilling and put employees at risk of strain or injury even when the associated weight moved is low. Interaction with greater weights and unsanitary environments are even more hazardous. Automation is highly suitable for such tasks which are commonly referred to as dull, dirty, or dangerous. Safety technology that enables human-robot collaboration allows this benefit to be applied to more manufacturing processes than ever before.

Take Advantage of Flexibility

Due to the ease of reprogramming the robot, it is possible to rapidly optimise processes or change the procedure to work with product variations. Mass customisation is a growing trend, with production lines becoming more high mix/low volume. Many cobots can save multiple routines, making it possible to move the cobot around the factory and have it perform different tasks at different times, even within the same day.

Get Return on Investment Faster

The ease of implementation and in-built safety features can vastly reduce the complexity of implementation which reduces costs. Reducing the time spent installing and configuring the robot cell also means the robot can start operating sooner, accelerating the return on investment.

Utilise Robotic Consistency and Human Intuition

Robots are fantastic for tasks involving repetitive, precision, or heavy loads. However, human intuition, decision-making, and dexterity is still beneficial in many processes. Robot cells designed with collaboration in mind enable a streamlined process of both robots and humans processing workpieces together.

Low-volume high-mix manufacturing is best performed by humans, and high-volume low-mix manufacturing is best performed by highly automated processes. When mix and volume are moderate (or uncertain), human-robot collaboration can balance cost, adaptability, manufacturing capacity and quality, enabling factories to take advantage of market opportunities like the increased market for customised products.

COMMON EXAMPLES OF ROBOTS IN COLLABORATIVE APPLICATIONS

Pick and Place

In this task, a workpiece is picked up from one location and moved to another. This process has all the right factors for successful collaborative automation: It involves highly repetitive motions moving weighted objects that leave people susceptible to strain and injury; The workpieces are typically moved in close proximity to people such as to/from their workstation; cobots can easily be reprogrammed and moved if the product line changes - pick and place operations are common so a new home for the robot can easily be found.

Packaging and Palletising

This task is a subset of pick and place tasks which could involve assembling boxes, shrink-wrapping, and moving packages onto pallets. The workspace is often more rigid and requires a large work area, making articulated robots especially suitable due to their extended reach. Finished workpieces can also be heavier, which larger articulated robots are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suited to handling. Automating this process saves people from performing repetitive heavy lifting.

Machine Tending

Machine tending involves:

- inserting workpieces into a machine
- operating the machine
- removing the workpiece
- tool changes
- cleaning

This process can involve long waits between stages. An articulated robot can be programmed to handle each of these steps automatically and for multiple machines to be used simultaneously, freeing up the human operator to perform other tasks. An increasing number of robots are also becoming compatible with portable workbenches, allowing them to be flexibly deployed to the most valuable position on the production line.

Some machines are a source of physical risk to operators, so automating this task can improve safety. Some end-effectors are designed with multiple attachments connected to the limb, allowing the robot to move new pieces to the machine and move completed pieces from the machine in a single trip rather than moving back and forth between each position, greatly improving cycle time. Another example would be to have a vacuum as a second attachment to clean the machine between operations.

Process Tasks

Process tasks involve using a tool on a workpiece, such as gluing, painting, and welding. The path of the tool is consistent and repeatable, making the process suitable for automation. Cobots can be hand-guided by tool-trained operators to learn the path, which it can then repeat for high-volume production, allowing the operator to spend less time performing repetitive tasks and more time on complex low-volume workpieces.

Finishing Tasks

While similar to process tasks, finishing tasks typically require a lot of force, making the process more physically demanding. Examples include polishing, grinding, and deburring. A significant amount of force is typically needed for finishing tasks, so using PFL method may not be viable, but a robot with PFL capabilities can instead use the in-built force sensors to measure and automatically adjust the amount of force applied to the workpiece. The nature of finishing tasks would require other safety methods to be implemented, such as fencing. A separate force torque sensor can be attached to the wrist of other robots to enable force measurement.

Quality Inspection

Combining robots with high-quality cameras or 3D scanners and machine vision can be used to enable automated quality inspection of workpieces.

Smart Workbenches

Assembly tasks using smart benches - workstations with integrated technology such as vision systems and smart tooling – are becoming increasingly supported by robotics. The addition of robotics allows a reconfigurable and multi-use tool that can support with pick and place, provide ergonomics support for the specific assembly tasks, complete in process inspection with vision systems, and physically assembly components while the operator is free to complete others.


FANUC Robot
LR Mate 200iD 4S
E107996

COMPONENTS OF A ROBOT SYSTEM

THE ROBOT(S)

The requirements of the manufacturing process dictate the most suitable robot or robots for the task. The reach of the robot is how far it can move from its default position while holding a tool or workpiece. The payload, or load capacity, is the weight the robot can safely carry (including the end-effector). The maximum speed of a robot will be detailed in the product specifications, but the actual operation speed will depend on its purpose. Robots in collaborative applications typically operate at slower speeds, which suit operations with slow cycle times, such as process tasks. The cycle time is the time taken to complete one iteration of a task, which can be improved through clever application design as well as the safe increase of robot speed. The robot will also have in-built safety features listed on its specification. Different robot configurations have varying advantages and disadvantages:

- Delta robots – often called spider robots for their appearance – use multiple lightweight parallel limbs to move the end-effector at very high speeds and with high precision, though they are best used for low payloads to keep inertia low and speed high. They also need to be located above the workpieces which may require a frame to be installed, but this utilises potentially unused vertical space.

- Cartesian robots - encompass their workspace with a gantry, providing a solid base that enables the rigid movement of very high loads at high speeds, though they are not the fastest configuration, and the gantry takes up a significant amount of space. Furthermore, the exposed slide rails are vulnerable to dirty environments.

- SCARA robots - offer greater precision than delta robots and greater load capacities but are not quite as fast - though they still operate at very high speeds. With just four axes of motion, these robots tend to be more affordable as well.

- Articulated robots - have fantastic manoeuvrability as they typically have six axes along its arm, which allows their end-effector to follow almost any path within the large workspace while moving and rotating simultaneously. Articulated robots can move around obstructions within the workspace such as reaching through and under the workpiece, into machines, or around other parts of the robot system such as conveyors and jigs. The complexity of motion possible also means that articulated robots can be slower than other robot configurations.

Cobot Configurations

Although any robot configuration can be used in a collaborative application with sufficient safety considerations, the majority of cobots on the market – with PFL built in and ergonomic surfaces - are articulated robots. These typically have payload capacities under 20kg, though companies are developing cobots with ever increasing capabilities while maintaining safety standards. These include the UR30 by Universal Robots, with a 30-35kg payload and maximum reach of 1300mm, and FANUC's CR-35iB, which has a payload of 35-50kg and reach of 1643-1831mm. Precision Automation have developed the PP100 – a cartesian configuration cobot, and Wyzo have developed a delta configuration cobot including a pedestal to place the end-effector above the workspace.

A robot system does not need to only have one robot working on the task. Having additional robots can allow more complicated tasks to be performed or increase the throughput of that particular stage of manufacturing. However, if the robots are operating within the same workspace, then care needs to be taken to ensure they do not collide or interfere with each other during operation. Robot suppliers typically provide software to allow robots to work in the same area without clashing, an example of this being Kuka's RoboTeam package.

END-EFFECTORS AND TOOLING

The end-effector enables interaction between the robot arm and the workpiece, allowing the robot to perform its task. It is essential that the end-effector is physically and electronically compatible with the arm, so many OEMs are partnering up to develop eco-systems of compatible parts, making selection and integration simpler. After selecting a suitable robot for the task at hand, the end-effector has its own limitations to consider. They have their own load capacity, accuracy, and repeatability limitations, and they must be suitable for the selected robot. The weight of the end-effector takes up part of the robot's payload capacity.
There are many end-effectors available for the huge number of tasks possible in manufacturing. When it comes to picking up objects, there are electric, pneumatic, vacuum, and magnetic grippers, in addition to scoops and other more niche gripper technologies. Each of these have unique capabilities, advantages, and disadvantages that should be considered depending on the application. End-of-arm-tooling is more intuitive, with tools for drilling, painting, gluing, welding, cutting, and more.

For collaborative applications, the end-effector must also be safe for proximity with people. Pinch points are a common risk where a body part becomes trapped between the end-effector and another surface or moving parts within the system, such as a gripper. Some end-effectors are designed with use in collaborative applications in mind, with rounded, padded edges and guarding for pinch points. Having compatible communication between the arm and end-effector is important to allow sensors to control both functions, such as to initiate a protective stop for both the gripper and the arm. Furthermore, the end-effector should have been designed so that loss of power does not result in a dangerous failure, such as dropping the workpiece.

End-of-arm tooling has even more potential for risk than grippers. Many tools are unsafe for proximity with people – it does not matter how slowly a blade or welding torch is moving, contact with a person will cause harm. Robots equipped with dangerous tools are likely to require fencing or other physical barriers during robotic operation, regardless of how safe the robot or the rest of the system is. Despite this, cobots are still popular for these applications. Hand-guidance can be used by an operator that is skilled in the task to program the optimal robot toolpath during the setup phase of the operation, with the robot then left to execute the repetitive task by itself while the operator handles more bespoke work.

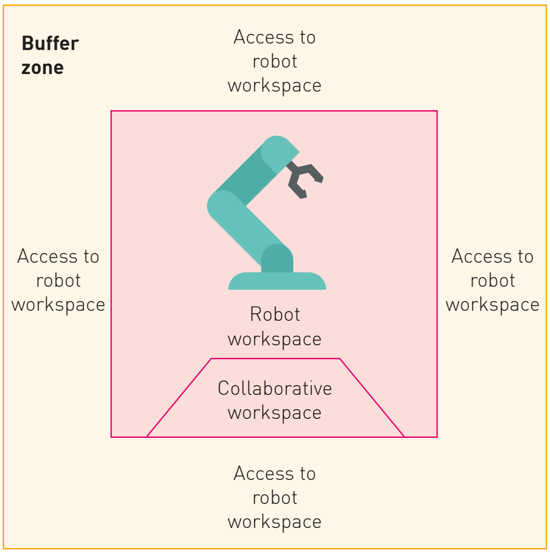
Many automated processes, particularly machine tending, utilise a single robot with dual (or more) end-effectors, increasing efficiency despite the low-speed movement of the arm. With two grippers, the robot can move two workpieces at a time or multitask, such as unloading and then reloading a machine without additional arm movements. Multiple grippers can also increase the payload capacity of the gripper and provide additional contact points for irregularly shaped items, though the added weight from the second gripper would reduce the robot arm's total capacity. The end-effectors can also have separate functions. Alternatively, automatic tool changers can allow the robot to change end-effector mid-cycle, switching between grippers or tools to suit each stage of the process.

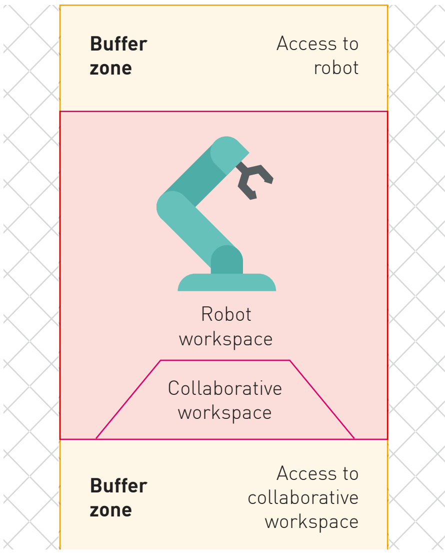
FENCING AND SENSORS

Fencing around a robot can help to prevent people, robots, and other hazards from entering or leaving the robot's workspace. Fencing may not withstand impact from more powerful robots, so the fencing needs to be positioned beyond the reach of the robot, end-effector and carried workpiece, and limitations need to be applied to the robot's position. Software limitations and mechanical end-stops and limit switches can achieve this. Screens and ventilation can protect passersby from hazards such as UV from welding, sparks, and fumes. The main function of fencing is to prevent access from people into the robot's workspace. Safety systems are designed to work in the event of both intentional and accidental actions. Sufficiently high fencing prevents any part of a person's body from accidentally entering the workspace, such as a hand raised to point. Intentional access is sometimes required for cleaning, maintenance, or reprogramming. In these scenarios, a protective stop can be initiated by door interlocks, light gates, and pressure mats. Lock out and tag out procedures can also be used to ensure dangerous equipment cannot be operated until access is complete, by isolating any power supplies.

A significant benefit of cobots is that a fence is often not required, although this also depends on the risk from other parts of the system. Some collaborative applications still benefit from fencing. For example, a robot and a person may share a collaborative workspace to load a workpiece onto the robot which then inserts it to a machine. This machine may be dangerous, so fencing can prevent the person from accessing it but still allow the robot access.

SSM uses vision systems or area laser scanners to detect the position of people relative to the robot system, slowing the robot down as a person approaches and speeding it up when there is a safe distance between them, as previously described. The robot must be able to come to a safe speed (or stopped entirely) before a person can enter the workspace, so there is a buffer area around the robot within which a person will cause the robot to slow down. Although fenceless coexistence can be achieved with SSM, foot traffic through buffer zones can slow down the robot unnecessarily. A physical barrier can prevent people from accessing the workspace, allowing the robot to move at full speed as a collision cannot occur. Selectively combining fences with SSM at designated collaboration zones can enable collaboration, reduce space requirements, reduce productivity losses from unrelated foot traffic, and maintain safety.





Robot slows

Robot stops

COMPLETELY FENCELESS
SPEED SEPARATION MONITORING

The buffer zone must be configured to include any direction from which a person can approach the robot. Without fencing, this results in a large area.

A person may walk near the robot to access the collaborative workspace, to perform maintenance on the robot, or to simply access another area of the factory. As they enter the buffer zone, SSM slows the robot.

PARTIALLY FENCED
SPEED SEPARATION MONITORING

Fencing blocks off unnecessary access points so the buffer zone only needs to be configured for smaller areas.

SSM now only slows the robot when necessary actions are performed, and operational efficiency is maximised.

Airskin is a pressure-sensitive, padded skin that can be applied to robots, end-effectors, and other autonomous devices to detect collisions with obstacles and people, similar to PFL. Industrial robots equipped with Airskin can move up to 6x faster than a cobot using PFL.

Solent Automation & Robotics have developed an all-in-one palletising solution using an industrial robot, where the entire robot cell is preconfigured and then delivered and installed in less than a day.

Sensors attached to the end-effectors are essential to ensure accuracy and safety. A relatively new technology in robot sensing is smart, padded skins. These can be applied to robots, end-effectors, and other autonomous equipment to enable them to stop moving when they contact an obstacle or person, similar to using PFL.

POSITIONING AND MOBILISING THE ROBOT

Articulated arms can be affixed to the floor, ceiling, or walls. Some types of robot are less flexible, such as delta robots which need to face the parts being picked up, typically meaning it is installed on a ceiling or gantry. The heavier the robot the more heavy-duty the installation needs to be which can be expensive and time consuming. They are also less suitable for use in collaborative applications due to the inherent risk of their mass and power, even at slow speeds. Cobots are typically much lighter, so are easier to install and reposition. Installing fencing and configuring locks and switches takes more time, further increasing the ease of installing cobots if the overall application does not require fencing. Some cobots are light enough to be installed on top of wheeled carts that can easily be manually repositioned around the factory. These carts can be quite advanced, with integrated power and communication ports and attachments for tool changing.

There are ways of automating the repositioning of cobots or adding further axes of movement. Although adding these layers of complexity has advantages, it also introduces further financial and implementation risk that would be best suited for companies experienced in automation adoption to undertake. Less experienced companies can utilise much simpler solutions initially, such as fixed-position robots and infrequent manual repositioning.

Automated Guided Vehicles (AGVs) or Automated Mobile Robots (AMRs) are even more advanced forms of wheeled cart. They are autonomous, driverless vehicles that can independently move around the factory and complete various tasks. They are collaborative, in that they share their workspace with people and use sensors to detect obstacles and people so they can avoid collisions. AGVs navigate a predetermined path using markers like magnetic strips and tracks, while AMRs use sophisticated sensors and path planning to navigate a dynamic environment. Rather than installing multiple robots across the factory for tasks that only require a short amount of interaction per cycle, such as certain machine tending tasks, a robot combined with an AGV or AMR can use the same arm for multiple tasks throughout the day. AGVs and AMRs are more commonly used without a robot arm attached, using their sensors to safely perform logistics tasks in warehouses or factories.

Every time a new robot application is implemented – whether that's a different workpiece, tooling, location, change in level of collaboration, or change in maintenance routine - a risk assessment must be performed to ensure safety.

If the robot's reach is insufficient, then installing the arm on an auxiliary axis can provide it greater reach in one axis. This will allow the whole robot to move up and down, or horizontally across the workspace. This could be cheaper and more practical than purchasing a robot with greater reach, however it is important to get an auxiliary axis that can communicate with the rest of the robot system to ensure safety operations function correctly. It can be complicated to integrate a robot with an auxiliary axis, particularly for collaborative applications, so a separate robotic positioner may be more effective. These robots have a limited number of axes for positioning and orienting the workpiece, working alongside the industrial robot to maximise the flexibility of the application.

MACHINES, JIGS, AND FIXTURES

Sometimes the simplest solutions are the best. Trying to use a robot to perform a task that a machine, conveyor, or other automation device can achieve might just overcomplicate the manufacturing process. Rather than overspending on an incredibly precise robot so the workpiece can be positioned exactly right, jigs and fixtures are a far simpler method to produce the same precision and repeatability, though this is not always appropriate for every application.

Existing equipment does not necessarily need to be replaced with the latest versions of machines that have designed for integration with robots, though the improved communication compatibility can help with automating the process. Articulated robots have the flexibility to open machine doors and reach inside, operating it like a person would

HOW STAFF INTERACT WITH THE ROBOT SYSTEM

Regardless of how automated the manufacturing process is, people will need to interact with the system at some point. Even fully automated cells completed isolated by fencing will require installation, maintenance, and retirement, with considerations for safe access at every stage. When the application is collaborative, the way people interact with it becomes essential to its efficiency and safety. The key to any effective collaboration is for the involved individuals (or robots, in this case) to only interact with each other when it is beneficial. If the robot is positioned so that it frequently bumps into the person, not only will the efficiency be reduced from constants stoppages, but it will be potentially dangerous and certainly annoying.

As mentioned previously, a fenceless application using SSM will slow down as people approach it. The efficiency of the system will therefore be reduced so measures should be taken to either avoid unnecessary foot traffic nearby or to prevent the irrelevant foot traffic from affecting the robot, such as selective fencing as mentioned in Fencing and Sensors.

Sequential cooperation should be intuitive, and the process should reduce the mental load for the operator, rather than require even greater concentration for long periods of time.

Ultimately, the robot system should be a tool used by employees to make production easier, safer, and more efficient. Consider the "user experience" of interacting with the system. The easier it is to use the system safely and effectively, and the harder it is to misuse the system (accidently or even intentionally), the better. Part of the user experience is effective training, which is discussed more in the next section. Additional training, PPE, and signage is required to minimise any hazard that cannot be eliminated through the design of the system or through adequate safeguarding.

DESIGNING AN AUTOMATED PROCESS

KEY THOUGHTS

Simple

"People often want to automate the hardest job in the factory," Mike Wilson, chief automation officer at MTC, says. "Often that's not the right place to start. There's a learning curve with any new technology. It's better to start with something a bit simpler."

Although it can be tempting to pick the most valuable task that has the highest potential return on investment (ROI), this task is often complex and difficult to automate. Automating the simplest task in the production process will provide a smoother introduction to automation within the company, minimising implementation time, risk of failure, and even investment cost, therefore providing a more rapid ROI.

After the first successful automation project, employees at the company will have gained valuable experience and understanding of automation. This opens the door for implementing further automation of even more valuable tasks, now with reduced risk.

Replicating a human's movements and dexterity can be a complicated task because robots and humans have different capabilities. Consider, instead, the actual requirements of the task rather than how a person performs it. This may mean not using robots at all – automation comes in many shapes, sizes, and functions. Automatic car washes do not use robot arms with hoses and sponges – they use rows of nozzles and cylindrical rollers with strips of cloth.

Likewise, it can be tempting to simply use a robot arm in a role where a staff member has retired or is ill, however, this is rarely an optimal utilisation of the investment. The production line can be redesigned with the robot performing a high-value function, freeing up staff to perform other duties where human intuition and adaptability is more valuable.

Holistic

The level of effectiveness of an automation project is dependent on all parts of the application working effectively. It is essential to consider the application all together – the robot, end-effectors, tools, safety features, workpiece, inputs and outputs, and human interaction. When considering human-robot collaboration, it is best to consider the application as being collaborative or not, rather than the robot alone.

The best way to understand the intricacies of a process is to involve the staff who currently perform the task. Work out what steps are the most dull, dirty, or dangerous, what steps they take, and what adjustments they make to the official procedure to ensure a successful outcome – whether there are specific movements and intricacies to processes to make them work, and how often they have to react to changing scenarios. Consider these factors when determining the task requirements and work together to find the optimal interactions between robots and people.

By involving employees in the decision-making process, they gain a better understanding of the task being performed by the automated system which can help ease concerns regarding how their role in the company might change. Interacting with the safety systems will demonstrate that their health and safety is being prioritised. Understanding how the robot and safety systems operate can also ensure that the robot system is being utilised safely, rather than safety features being bypassed, or the robot being ignored for being perceived as inconvenient to use.

Appointing an "implementation champion" to lead the automation adoption project provides an opportunity for an enthusiastic employee to upskill and can help draw knowledge and skills into the company to support future maintenance of the system and provide a better foundation for future automation projects. It is incredibly beneficial to retain the skills and knowledge of other employees too as they can provide valuable insights into past, present, and future manufacturing processes at the company.

Staff will need to be trained to use the robot system safely and effectively. Robot arms come with an instruction handbook that contains instructions for safe operation and maintenance including how to respond to emergencies or abnormal situations. It should also detail the required training for operators to achieve the necessary level of skill. However, training must also be provided for the other parts of the robot system and the robot system as a whole, rather than only for the arm. Since the automated process is typically an alteration of a pre-existing process, some of this training will already be done. In-person demonstrations and practice are highly valuable when training staff to use potentially dangerous equipment.

COLLABORATION AND SAFETY

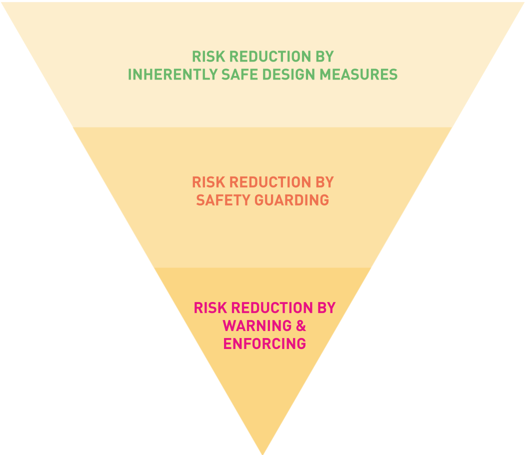
Using cobots can make it easier to safely implement human-robot collaboration, however it may not be a suitable choice if:

- The task requires high speed operation – cobots using PFL operate at slower speeds to minimise injury in the event of a collision.
- The workpiece is heavy – cobots generally have a lower payload capacity than industrial robots. The greater the mass of the workpiece in a collaborative application, the slower the robot is permitted to move for a collision to cause no harm to a person.
- The workpiece or robot tooling are dangerous – Collisions or even working in proximity with certain workpieces and tools are dangerous even when the robot is not moving. The following hazards are common examples of what to consider:
    - Sharp edges or points from knives, blades, and saws
    - Heat emissions from blow torches or metal annealing
    - Bright lights from welder's flash and lasers
    - Chemical or particulate emissions such as steam, solder fumes, dust and sawdust
- The robot needs to operate above shoulder height – head collisions must not be possible at any speed.
- The application does not benefit from collaboration with people – it may be safer, simpler, more effective to use a cheaper industrial robot with safety fencing.

In these scenarios, a traditional caged industrial robot may be a better choice, or the process should be kept manual with sufficient PPE and training. On the other hand, cobots can often operate within a cage with PFL disabled so they can operate at higher speeds. This enables the ease of installing, programming, and redeploying cobots to be utilised while still having high-speed automatic operation. This can be done with some cobots using hand-guided training, however the power and force limits of some cobots are mechanical maximums rather than software restrictions, so they will always be speed limited.

The most important step in designing any automated system, especially for collaborative applications, is to **perform a risk assessment,** which suppliers and integrators can support with.

After identifying hazards, the best course of action is to eliminate or minimise them. If this is not possible, then safety guarding needs to be put in place to physically restrict access, and if access is required then ensuring staff are informed of the dangers and reminded by signage can help to mitigate the risk.



FINANCE

Purchasing a robot arm outright can be expensive, but there are ways of reducing this lump sum cost. Robot arms are reliable and long lasting so can often be purchased second hand, though there will be less support available from the OEM. Many companies offer finance options such as leasing, including as a yearly payment or even as an "hourly wage", making it comparable to the cost of an employee. Although financing can cost more in the long-term, the short-term cash flow benefits reduce the risk of the investment, increase the speed of ROI, and can bring the implementation and benefits of automation sooner. The ease of use of cobots means they have a much shorter ROI than traditional industrial robots, making them more appealing for investment. Robots as a Service (RaaS) is also becoming popular as it reduces the financial barrier to entry for adopting automation while also providing a level of service to SMEs to reduce the need for internal technical skills.

SUPPLIER AND INTEGRATOR SELECTION

A robotic system is a major investment with significant benefits if implemented effectively, but there are a lot of possible options and many safety considerations that need to be accounted for. It is prudent to gain support from an integrator to assist with installation.

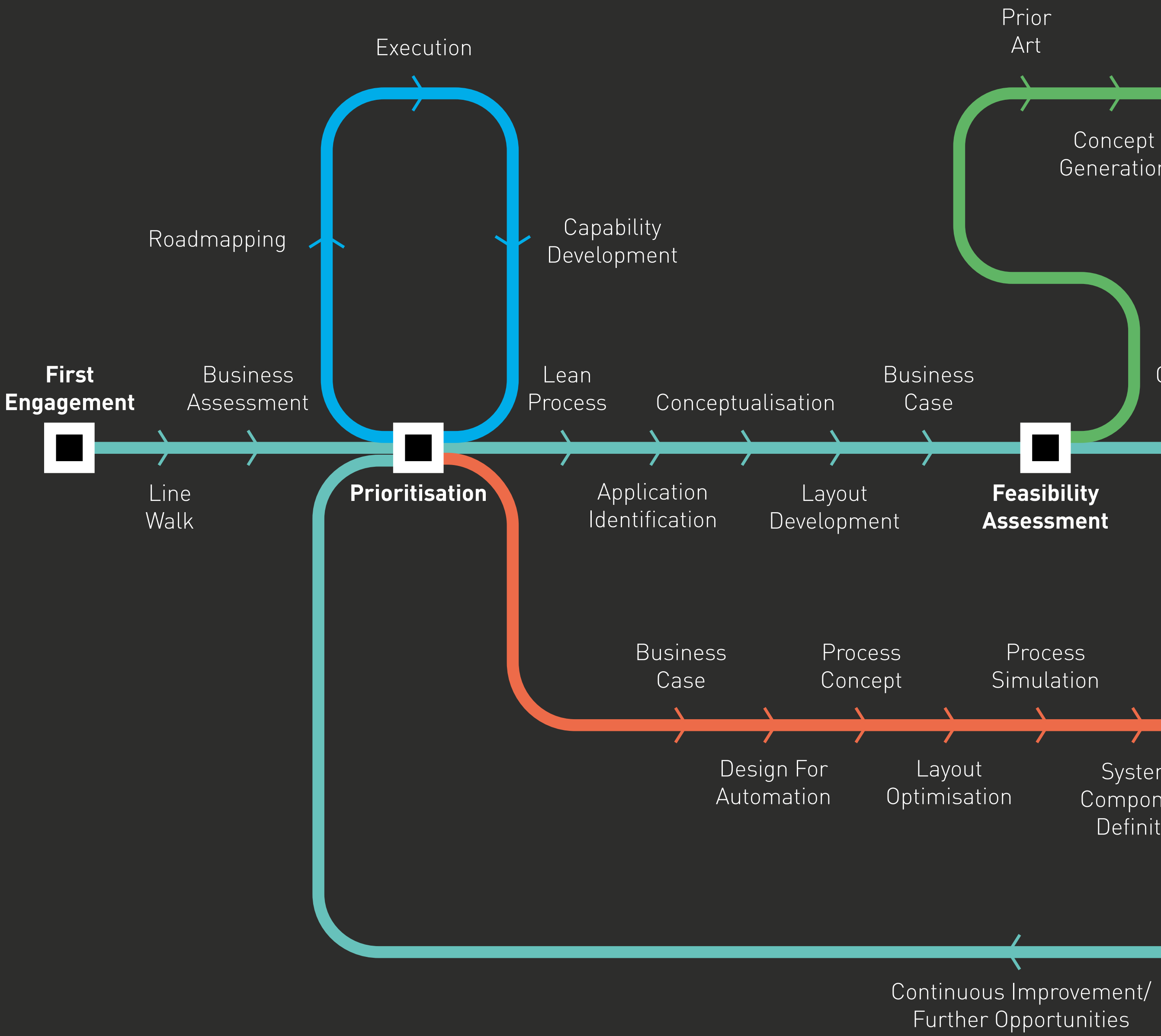
The MTC specialises in supporting businesses through their automation journey. Starting with a line walk to understand the business and discover opportunities, our Automation Transformation team will help process a feasibility study, generate concept designs, and review the business case for automation. We can assist companies with producing a User Requirements Specification to inform potential integrators of exactly what is required of the automation system to ensure that companies get the best return from their investment. We are vendor-agnostic, so we help connect companies with the suppliers and integrators that work for their technology requirements, price, and industry.

Component Compatibility

Not all components of a robot system are inherently compatible – especially if produced by different manufacturers – this being said, many robot arm manufacturers such as FANUC and ABB have started to develop eco-systems of suppliers to make selection and installation of compatible devices much simpler.

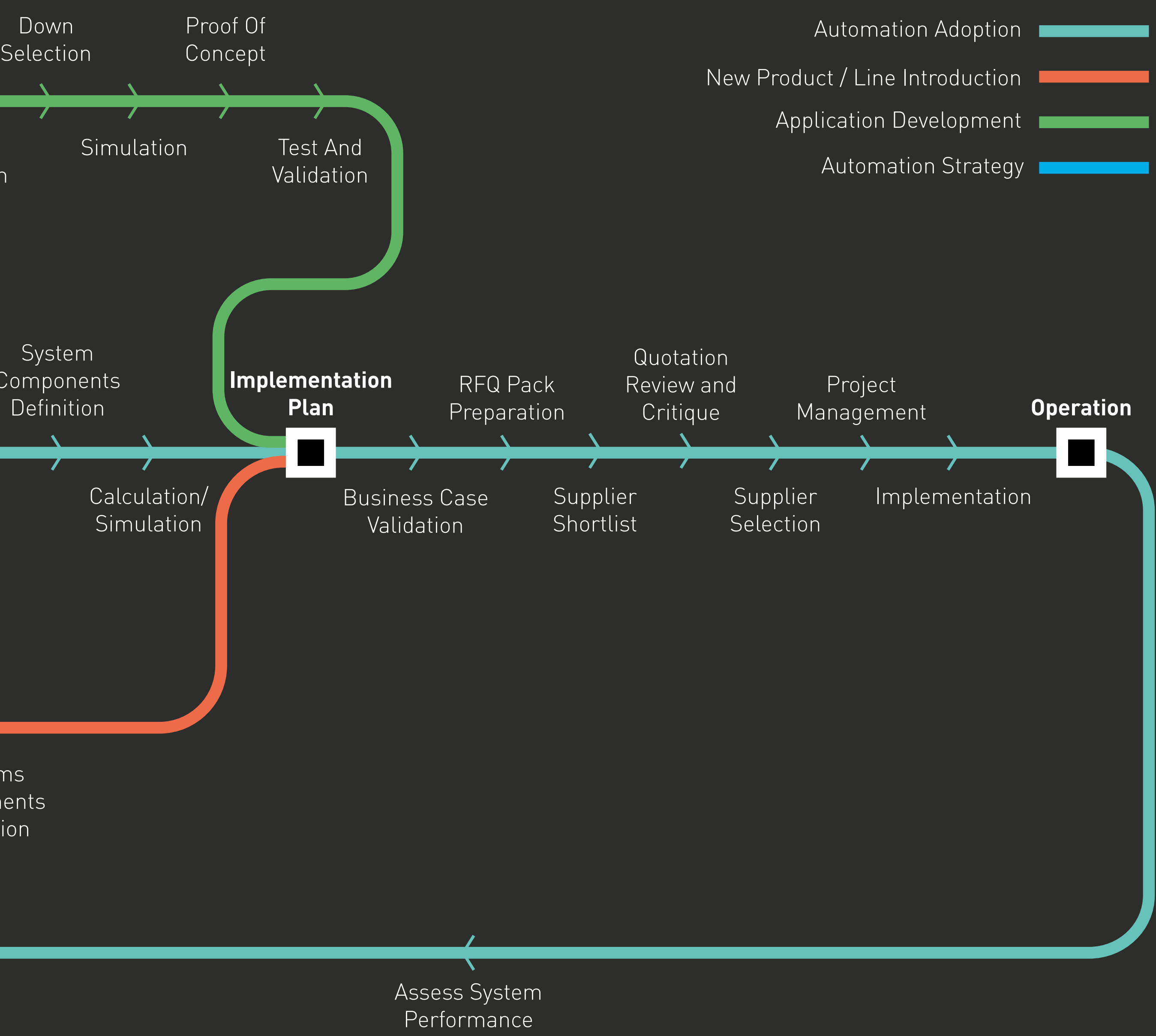
THE AUTOMATION JOURNEY

The need to improve manufacturing and increase productivity through the use of automation is becoming increasingly important, with many companies now seeking to understand how best to progress. There are many ways robotics and automation applications can be deployed to improve productivity, provide consistent quality, and undertake arduous, mundane, or dangerous tasks. Automation isn't about replacing jobs, but providing the UK workforce with the tools it needs to be productive.



There is a steep learning curve associated with the adoption of robot automation. The process involves many complex steps, beyond just the operation of the system once it is installed. The Automation Journey is an initiative by the MTC to provide impartial expert advice and guidance on the automation journey for manufacturers in the UK. Through this journey, the MTC aims to develop informed automation clients who can implement the future successful projects independent of their support.

The Manufacturing Technology Centre is uniquely placed to help any business considering an investment in automation, particularly those who are taking these steps for the first time, like CBE+. The MTC works with businesses, both large and small and across a wide range of sectors, and aims to help them manufacture faster, at a consistently higher quality and lower cost, achieving performance improvements for their business.



CASE STUDY: CBE+

The MTC partnered with Chesterfield-based SME CBE+ to support the business on its journey towards implementing automation and robotics. CBE+ came to the MTC because the business wasn't sure where to start with automation. Following the Automation Journey, the MTC has helped CBE+ specify an automated system which will help meet growing demands for its products and services, which include electroless nickel plating with complimentary metal testing, precision engineering, gear cutting, wire EDM, assembly, heat treatment paint and pressure testing, all from a single location.

The primary challenges CBE+ looked to address were in relation to the volume of parts being processed. The business wanted a robotic system to help with loading and unloading nickel plating lines, as large orders from customers in new sectors had driven the need to explore new ways of working. The task of loading and unloading parts was repetitive and not the most valuable or rewarding use of employees' time, with some colleagues picking parts from a box and placing them on a rack for entire shifts. It was also physically demanding, with a lot of physical movement required to load the rack. An automated system was needed to improve the efficiencies of the task, reduce the manual labour required, further increase health and safety standards and better maximise the skillset of CBE+ staff.

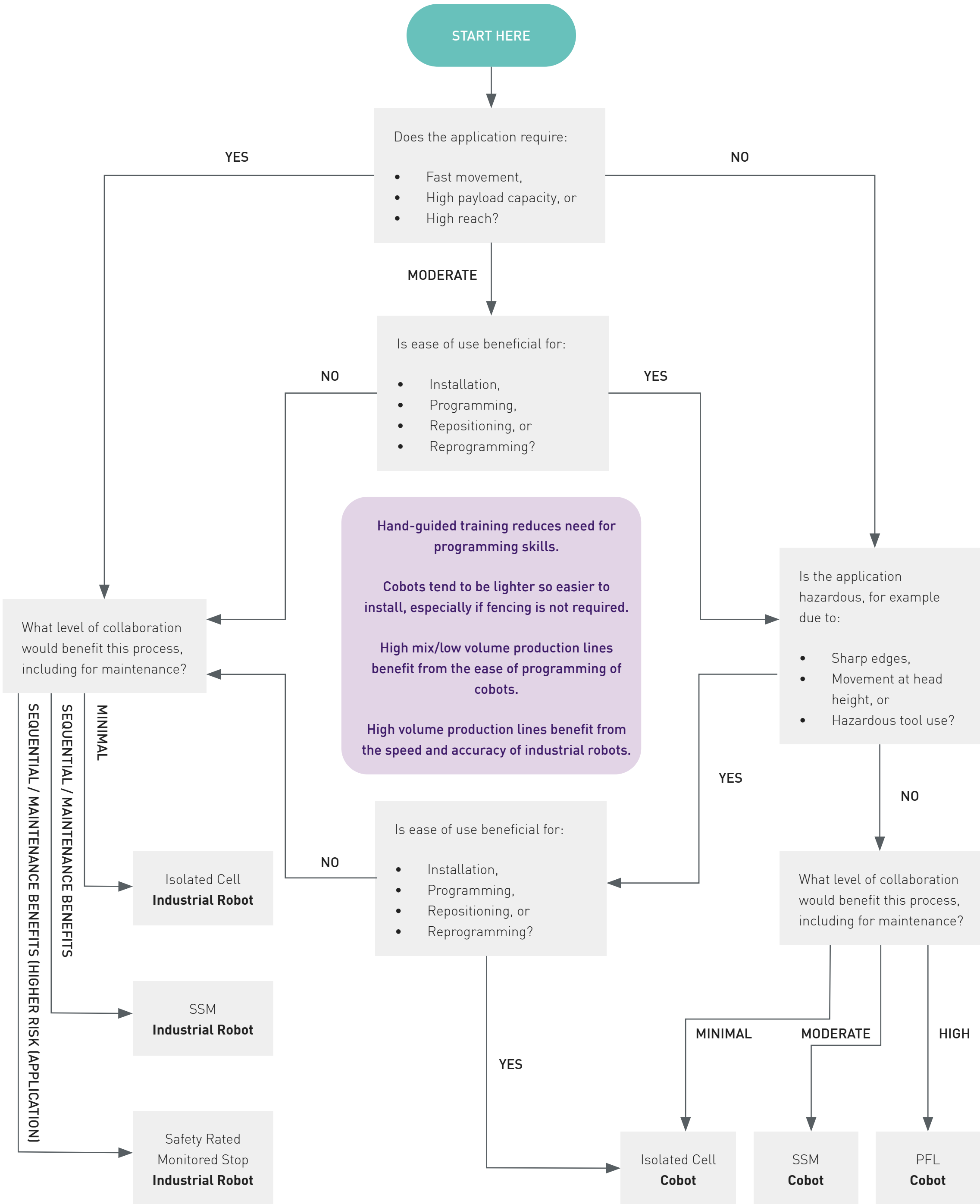
The MTC provided support with initial research in demystifying the options available and building the business case. The MTC worked to collate the requirements for the new system and approached several robot integrators and machine builders who could offer solutions to meet the requirements of CBE+. After receiving quotes from these suppliers, the MTC aided in understanding the options and selecting the right solution for CBE+. Based on the success of the project, CBE+ envisages a longer-term partnership working with the MTC to introduce automation into other sectors of its factory.

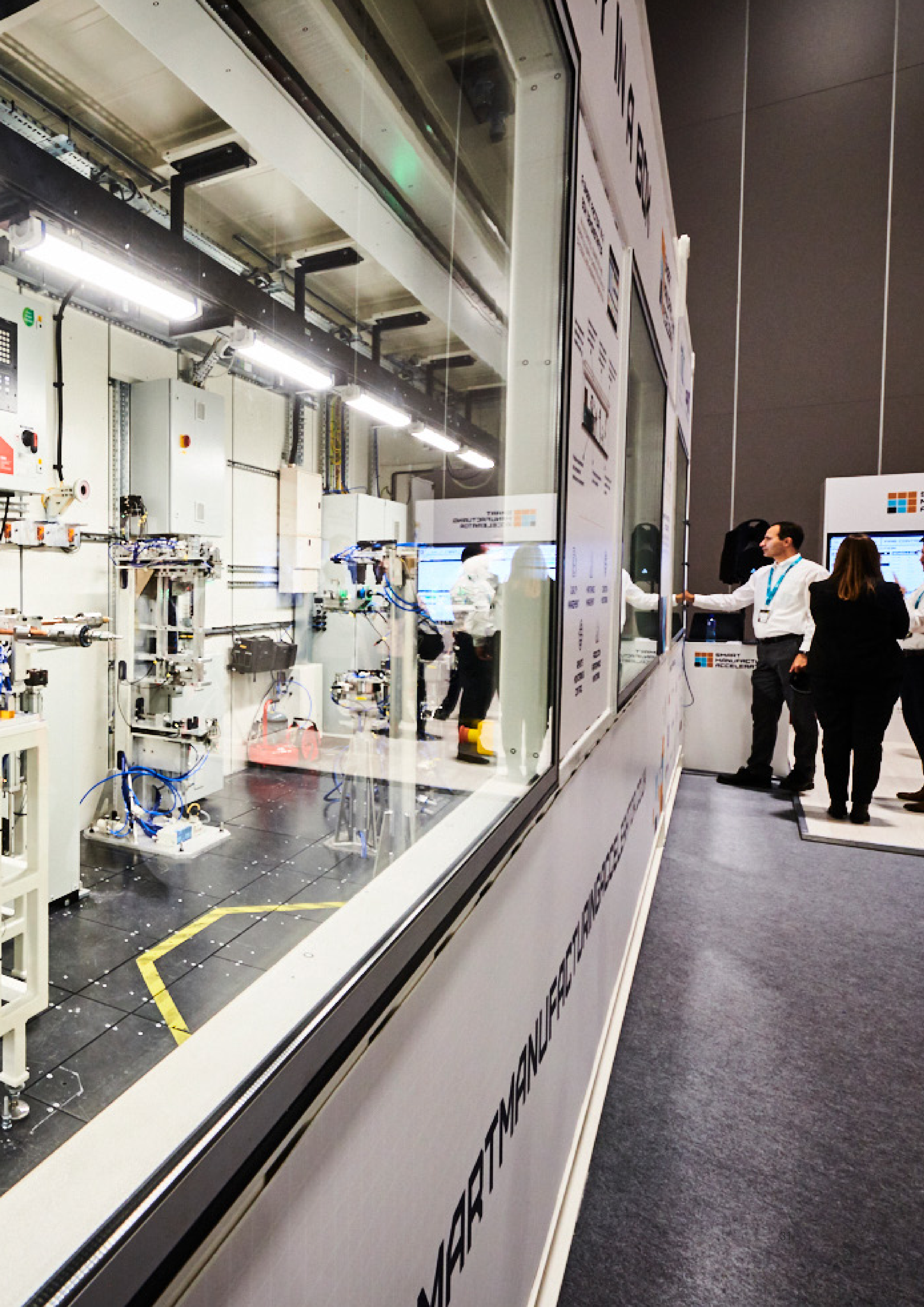
KEY TAKEAWAYS AND FURTHER EXPLORATION

The use of robotics and automation can significantly boost productivity for manufacturing companies and support with dull, dirty, and dangerous tasks. One of the key issues is that many find it difficult to identify opportunities to integrate automation or are reluctant to invest due to concerns over technical risk, a lack of internal skills to handle new technologies, high initial setup costs and long payback periods. Hopefully through reviewing this guide you have been able to; develop an understanding of how to optimise the implementation of robots in collaborative applications; learn the differences between robots and robot systems and the concept of human-robot collaboration; alleviate common misconceptions and demystify some of the language used; understand the importance of each part of a robot system and how they all interact in terms of human-robot collaboration and safety; gain information on the process of implementing automation and human-robot collaboration.

To further support with the adoption of automation and robotics, the following flowchart summarises which robot application might be best depending on the process you are looking to automate. For more information about any of the content found within this guide, or for any support needed in starting or progressing your automation journey, please reach out to the MTC through the automation and robotics section of our website.

https://www.the-mtc.org/what-we-do/technologies/automation-robotics/


START HERE
Does the application require:
Fast movement,
High payload capacity, or
High reach?
YES
NO
MODERATE
Is ease of use beneficial for:
Installation,
Programming,
Repositioning, or
Reprogramming?
NO
YES
Hand-guided training reduces need for programming skills.
Cobots tend to be lighter so easier to install, especially if fencing is not required.
High mix/low volume production lines benefit from the ease of programming of cobots.
High volume production lines benefit from the speed and accuracy of industrial robots.
What level of collaboration would benefit this process, including for maintenance?
MINIMAL
SEQUENTIAL / MAINTENANCE BENEFITS
SEQUENTIAL / MAINTENANCE BENEFITS (HIGHER RISK (APPLICATION)
Isolated Cell Industrial Robot
SSM Industrial Robot
Safety Rated Monitored Stop Industrial Robot
Is the application hazardous, for example due to:
Sharp edges,
Movement at head height, or
Hazardous tool use?
YES
NO
Is ease of use beneficial for:
Installation,
Programming,
Repositioning, or
Reprogramming?
NO
YES
What level of collaboration would benefit this process, including for maintenance?
MINIMAL
MODERATE
HIGH
Isolated Cell Cobot
SSM Cobot
PFL Cobot



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