CASE STUDY

MULTI-AXIS ROBOTS FOR ASSEMBLY AUTOMATION AND AUTONOMOUS GUIDED VEHICLES IN MANUFACTURING (ID4)

1 Introduction

Automating tasks through technological advancements has been an ongoing process in many industries. This development can also significantly impact occupational safety and health (OSH) in a work environment. It enables the removal of workers from hazardous situations and can improve the quality of work. This can be accomplished by automating cognitively strenuous tasks using an artificial intelligence (AI)-based system or by 'delegating' repetitive tasks to accurate and tireless machines like intelligent robotic systems. Some tasks might not be fully automated, but workers can still receive support through, for example, collaborative robots (cobots) operating in a shared space with workers. An increasing number of companies employ AI or advanced robotics. Although still in their infancy in terms of deployment, AI-based systems for the automation of both cognitive and physical tasks, as well as intelligent cobots, show promise in a variety of sectors. However, more information is needed on how they are implemented and managed in the workplace to help ensure workers' safety and health in present as well as in future applications.

EU-OSHA has developed a number of case studies with the aim of investigating the practical implementation of AI-based systems for the automation of physical and cognitive tasks and of intelligent cobots in the workplace, their impact on workers, how OSH is managed in relation to such systems, and to gain a better understanding of the drivers, barriers and success factors for the safe and effective implementation of these systems.

To develop these case studies, several key informants at the EU and international levels, such as workers' representatives and industry associations representing the targeted sectors, were consulted. Initially, 16 cases were identified and preliminary information was collected through a questionnaire. Hereafter, 11 of them were further developed into cases studies, including higher levels of information collected at the workplace level.

2 Methodology

The primary data source for the case studies was interviews held with different stakeholders within companies. For each case study, up to five interviews were conducted with workers of the company from different work areas. The participants included operators, data protection officers, health and safety engineers, managers work-councillors and technology officers.

The interviews had a duration of 1-1.5 hours each and were performed in the participants' native language, if possible, or alternatively in English. The interviews were conducted using an interview guide, while the results of the interviews were anonymised.

3 General company description

The presented company is a conglomerate focusing on a variety of sectors. It specialises in automation and digitisation in industry, infrastructure for buildings, decentralised energy systems, mobility solutions for rail and road traffic, and medical technology. Founded more than 150 years ago in Germany, the company now has branches in over 190 countries and employs more than 300,000 workers worldwide.

This large enterprise focuses on global goals when it comes to technology and innovation. They aim to create outstanding and high-performing technology and products for their users and customers. They have a strong focus on future development and aim for engineering excellence, high standards, teamwork and sustainable practices. Furthermore, ethical practices, integrity, setting high goals and creating a sustainable future are part of their core values. The company sees it as theirs and everyone's **responsibility to** comply with the **ethical industry standards**. This translates into no unethical behaviour that has the potential to put the users' wellbeing at risk being acceptable within the company. They also strive for **excellence in their services and products** by addressing customers' specific needs and providing the best solutions for them. Lastly, they heavily emphasise the importance of **continuous improvement and innovation**. This not only benefits their clients but also holds the potential to have a positive impact on the future in general through technology.

This case study focuses on one branch of the company located in Germany, specialising in **digital transformation**. The branch produces parts for industrial switching technology, circuit breakers for industrial applications, infrastructure and buildings, with a variety of over 1,200 different products. Next to efficient production, the branch's secondary purpose is to provide a possible blueprint for **the future of digital factories**. This is achieved by in-house developed hard- and software solutions, state-of-the-art industrial communication technology and specialised cybersecurity solutions. Within the location, a variety of different AI applications as well as advanced robotics are being used, tested and created.

The branch predicts that in the future there will be more robots, cobots, driverless transport systems and smart manufacturing systems, not only at their location, but in general. They see application for both **AI-based systems and advanced robotics in value-creating activities, logistics processes, ideal just-in-time material processes, customer delivery and human resources**. A variety of software solutions are being looked at in order to automate beyond production.

One of the core values put forward by the interviewees is the concept of 'lifelong learning', which is reflected in several places when it comes the implementation of advanced robotics in the workplace.

3.1 Description of the system

While some of the devices produced in this branch are still assembled manually, most of the assembly process is automated using **six-axis articulated robots** or **four-axis scale robots**. Smaller robotic systems are also being used to automate individual tasks. The branch is using industrial and lightweight robots, as well as **cobots**. These systems are purchased from third-party suppliers but maintained and programmed by the company to suit their specific needs. In addition, there are some robotic applications that are **self-designed and developed** by the company. They are used primarily for assembly processes. One task these **robotic systems** are being used for is moving work parts. Some components arrive on rolls that must be moved from the initial transport box onto a processing surface. The robot has to recognise the roll through an included **vision system** and place it onto the next processing surface. The vision system used in this robot is supported by a **self-learning system** so that it can recognise the roll, its position, and how to lift it effectively and safely. The vision system was trained on input data and can continue to improve, the more input it gathers. In this case, the worker no longer performs tasks related to this production step but is instead reassigned to other tasks, like the assembly of products for which the robotic system provides material. Should there be an issue with the robotic systems, workers have also been trained to repair them or solve software issues to a certain degree.

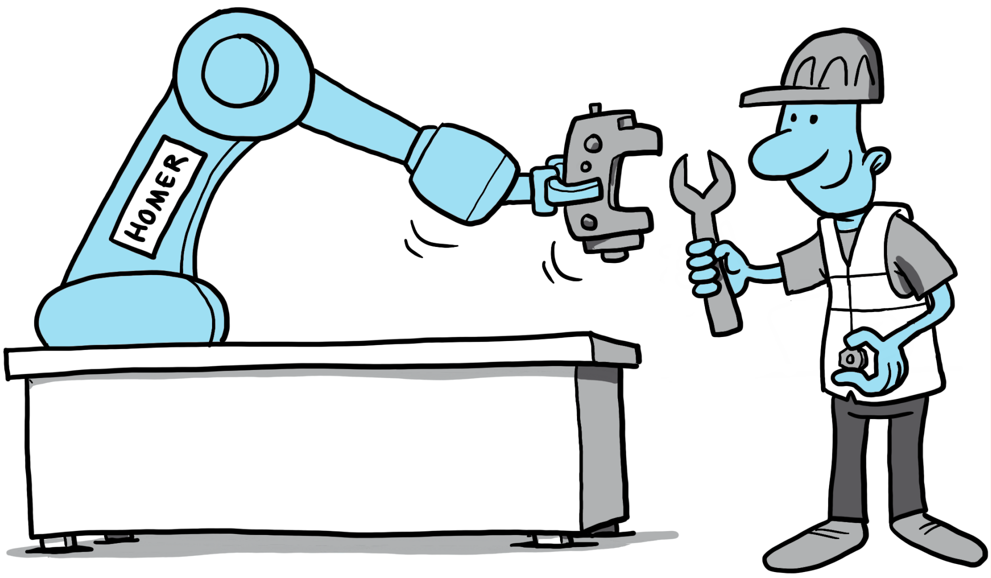
The primary need for the robots is to automate assembly tasks. This includes disassembling individual parts, assembling single parts and the packing processes as well as the testing and quality control processes (cognitive task). A large number of **automated visual inspections** are carried out by AI-based systems. Direct interaction with the robotic systems is rare because **production cycles are very short**. However, some **cobots are used in a slow-cycle process**, which is where human–robot interaction comes into play. Here, worker and cobot work on the same workpiece, where the cobot typically provides physical support by holding the workpiece. This allows workers to perform difficult assembly tasks more easily and without the strain of lifting the workpiece. In those manual workplaces, there is a lot of **adaptability to physical needs** (such as desk height), but the process and production speeds are often not adaptable. Cobots can carry out tasks like picking up workpieces, holding them for inspection or automating parts of the assembly. The cobots' purpose is to alleviate physical strain on a worker, and assist them in their main task, by reducing physical load. In these cobot workspaces, **workers still generally perform their previous task, or take on additional skilled tasks** in the assembly process. The assembly of certain parts requires skilled workers, whereas the process of lifting and holding the workpiece supports them in this process. It improves their quality of work, from both the workers' perspective and the product quality.

Besides robotic systems, the branch also employs **autonomous guided vehicles (AGVs)**. These are mobile robotic systems that bring material from a removal point to a target point. They are supported by a displacement sensor (a device that measures the distance between the sensor itself and surrounding objects by detecting the amount of displacement through a variety of inputs, such as linear proximity and ultrasonic displacement). These AGVs are purchased from a third-party manufacturer, but the paths they take through the production site are programmed by the company itself. Integrating AGVs into a running factory setting requires prior consideration regarding their interaction with the environment. As they are non-stationary, several considerations have to be taken to program their **paths safely as well as effectively**. This includes their behaviour in case of an unexpected collision, as well as optimal energy usage relating to when and where they can charge, so that the **system does not become an obstacle**. Workers also need to be made aware of an autonomously moving system in their larger work vicinity.

The primary point of interaction between an AGV and a worker is the worker using the system to have **parts delivered to or retrieved from a workstation**. Similar to the cobots, the AGVs enable the worker to perform their main tasks more efficiently, by automating an unskilled task. While it is possible to load an AGV manually, most have the ability to load items themselves, automating both the **transportation task** as well as the **lifting, loading** and **unloading tasks**. At these workstations, the worker now has more time to focus on the assembly task, rather than the continuous supply of parts.

A cartoon-style representation of the system, performed tasks and interaction with workers, including some of the challenges and opportunities for OSH is presented in Figure 1.

Figure 1. Multi-axis robots for assembly automation in manufacturing



3.2 Taxonomy-based categorisation

To categorise different types of technology, a taxonomy specific for different important criteria of AI-based systems and advanced robotics was developed by EU-OSHA.[1] This taxonomy includes, among others, the type of backend and frontend being used and the type of task performed, as well as which category it falls under (information-related, person-related or object-related). It distinguishes between routine and non-routine task characteristics as well as the degree of automation in the form of assistance or substitution. Finally, the taxonomy takes into account different OSH dimensions (physical, psychosocial and/or organisational) that are impacted by the technology.

[1] EU-OSHA – European Agency for Safety and Health at Work, *Advanced robotics, artificial intelligence and the automation of tasks: definitions, uses, policies and strategies and Occupational Safety and Health*, 2022. Available at: https://osha.europa.eu/en/publications/advanced-robotics-artificial-intelligence-and-automation-tasks-definitions-uses-policies-and-strategies-and-occupational-safety-and-health

Figure 2: Taxonomy for AI-based systems and advanced robotics for the automation of tasks

The cobots in this case study perform a **manual task** with a **non-AI backend software**. They perform an **object-related**, **repetitive (routine)** task with **physical** manipulation of the workpiece. The lifting part of the assembly process is substituted by the robotic system, however, the primary goal for lifting the workpiece is the inspection process. This process is still performed by workers and the robot **assists** them by lifting the workpiece for them. The latter-described OSH dimension, which is impacted by the cobot, is primarily **physical**, however the company also describes some effects on the mental state of the worker, so **psychosocial** effects can be included in the categorisation. Other robotic systems at this company's factory that primarily focus on the relocation of workpieces have self-learning systems included. Through visual input, they recognise parts and adjust their movements accordingly. They also perform the **manual task** of lifting workpieces, however this is only possible due to an **AI-backend software**. Still, the type of task is an **object-related**, **repetitive substitution** of **physical labour**. The AI-based system is not used to automate a cognitive task but to enable the robot to perform the physical task

The AGVs **fully automate** the **manual task of transportation**. Their sensors, however, use a **non-AI-based backend**, both to navigate through their environment and to locate and identify their payload. Their tasks are **object-related** and have a certain degree of repetitiveness, even though it is lower than that of stationary robotic systems. The OSH dimensions impacted by the AGVs are primarily **physical** for the worker; however, as they lead to a restructuring of work processes, some **organisational** changes apply.

Since these technologies have been introduced, the general work activities of shop floor workers have changed. Interviewees in administrative positions reported that their activities did not change, even though there were considerations for robotic technologies. This, however, only changed their task content, not the task itself. Hence, shop floor workers directly interacting with the systems are the most heavily impacted when it comes to their work activities. Cycle times and the provision of material have changed in such a way that robots, specifically the sorting robot, can work overnight or while the worker is on break. Pre-processed material is then always available for further processing. The work cycle for workers was not shortened, as the robotic systems were integrated into a pre-existing production line.

The impact on **job content and routine for workers** depends on which system they are interacting with.

For some workers, the introduction of lightweight robotic and collaborative robotic systems meant a change in **qualifications**. They received training to be able to perform maintenance tasks on the robotic system. Others were trained to be so-called key users for certain technologies (like robotics or 3D printing) and thereby be primary points of contact for operators and other workers, regarding suggestions for further automation including this technology or general support questions. Additionally, there is now a separate department that solely installs and adjusts robotic systems.

One of the most prevalent changes is that prior to the robotic automation, one worker made the product from start to finish, while now workers only contribute around 60%. They now perform additional side tasks while robots do the rest. Related to this change, material and tasks are now more distributed throughout the production site. While before a workpiece was completed at one workstation, this is no longer the case, as material is now distributed, to fit the new production line. Workers also have to be trained for the new technologies, so their routine is constantly changing and adapting.

4 Implementation process

A key factor for the successful integration of technology into a new work environment is the implementation process. Several factors, such as the identification of objectives and goals prior to implementing the technology, design decisions and participation, worker involvement and training, as well as the inclusion of guidelines or legislation, can influence it. In addition, some of the most important steps are the assessment of whether the intended goals have been reached, documentation of what challenges were faced, and finally consideration of how these lessons influence future company plans regarding the implementation of either new systems or more of those already implemented.

4.1 Motivators and goals

*Setting **goals** prior to implementing a technology can help quantify the success of the implementation and also inform what kind of technology is needed to reach them*. The interviewees expressed a number of objectives and goals for the introduction of the cobots, robotic systems and AGVs.

Economic goals, like an increase in production, cost reduction, increased flexibility of production and increased product range as well as the ability to produce in smaller batch sizes with greater variation, motivated the change towards more heavily automated production. Continuous innovation through advanced robotics is also intended to ensure that the company stays competitive within its field in the future. Increasing worker qualifications and further training of existing workers was listed. From a workers council perspective, preparing workers for future jobs is of high importance.

Speaking more generally, when introducing a new technology there is the expectation and goal from both the workers councils and management that it will **benefit the wellbeing of the workers**. The cobot reduces physical strain on the worker, leading to possible positive health benefits in the future, as well as an overall more ergonomic workplace. It can also reduce the risk of injury, as there is no risk that the cobot will drop a workpiece due to mishandling or muscle fatigue. AGVs reduce walking distances for workers and free them from carrying workpieces for a prolonged period of time. Based on the initial experience with the system, these goals seem to be achievable once routine has set in.

While the interviewees reported that the company has already met significant goals, they also highlighted that automation is an ongoing process and there are still gaps that need to be filled. The impact of certain measures can only be evaluated over time, if at all. While an increase in production and output was quantifiable, how well adjusted both workers and production lines are in terms of future economic prospects will only become clearer after time has passed.

4.2 Implementation

Before a new technology can be introduced into a workplace, there are a variety of factors to consider and often several stakeholders to involve. The implementation process can differ from company to company. With AI-based systems and advanced robotics being so customisable in their application, the general implementation differs for each case study. Nonetheless, there can be common implementation steps taken, with regard to who is involved in the process. The standards considered to implement a technology are equally important, both with regard to which are widely used and which are relevant to a specific case study. Furthermore, the individual difficulties and challenges are as vital to understanding the success of a case study as the ones more broadly shared among several case studies.

For this case study, the first step is an impulse for change. This impulse can come from a variety of sources. The company **explicitly encourages workers** to bring forward ideas and suggestions for further process automation. However, the initiative can also come from management. The suggestion is then introduced to the relevant stakeholder. Who needs to be involved strongly depends on the extent of the suggested project. The company differentiates between different types of change. Is it a new development, further development or an adaptation of existing infrastructure? Based on this, a project team is created, including a project planner, workers on site and advisory security engineers. A concept is developed based on the initial impulse. As this plant is capable of developing its own technological solutions, the project team then decides whether to develop externally or internally. This initial plan then goes through another project planning committee, cost estimates are obtained and construction approval is given. Based on this, simulations can be created. An initial **risk and safety assessment** is also carried out. If everything is approved, supplies are ordered and set up. After initial test set-ups, preliminary factory acceptance tests are carried out. At this stage, the future operators are involved and asked for their feedback on the system, including OSH concerns. The system is then finalised and final test runs are carried out. If the test runs are successful, a primary release is carried out. The system is set up on site and a real-time functionality test is carried out in which the system is tested under real conditions. This also includes an additional assessment of occupational safety. If the test runs are completed successfully, the system is considered safe to use. The final step before full use is **training** courses for the workers. In these, they learn how to use the robot both **effectively and safely**.

4.2.1 Implementation steps

To implement a new technology, a machine introduction process was created in which all stakeholders relevant to a project are defined and involved. Any change to an existing system or a new one starts with an impulse for change. This impulse can come from any worker in the company. Within the larger process of digitising the production line, some workers have been qualified to be key users (for example, for robotics or 3D printing) and thus become points of contact for change suggestions. Workers can request a robotic system workstation from the key user, who then makes an initial assessment as to whether this is feasible. If it makes sense, the suggestion is forwarded. These key users exist at different levels of the plant and are currently more than 15 people. Based on this, a project team is created, including a project planner, workers council member and data protection officer on site, and advisory security staff. Based on the need identified by the impulse, a concept is developed. Next, the project team decides whether to develop the solution externally or internally. Final approval of this solution must be given by the project planner for construction approval to be given. Based on this, simulations are created and possibly a test set-up in a laboratory environment. An initial risk assessment of the workplace is carried out and cost estimates are obtained. If everything is approved and management agrees, the relevant parts can be ordered or self-produced. The next step is set-up and then a preliminary factory acceptance test is carried out. If no need for change is identified at this stage, the system set-up is finalised and test runs are carried out. Physical systems are set up on site and a real acceptance test is carried out in which relevant functions are tested under real conditions. This also includes an **on-site risk assessment** to ensure occupational safety. Finally, before workers operate the system, they must attend training courses. Once the system is operational and fully rolled out, it is fixed in the work process and **mandatory** to use, as the products and the production process are optimised. But still there are some steps during the assembly process in which use of the cobot is optional. This applies to small batch sizes specifically.

4.2.2 Standards and regulations

To safely implement cobots and other robotic systems, a number of standards and regulations have to be considered. Ensuring that all relevant and applicable standards and regulations are considered during development and upheld during implantation and use falls under the jurisdiction of the company's occupational safety officers. Next to following the legal frameworks for robotic systems in the workplace, there are advisory recommendations from within the company. Furthermore, recommendations made by **universities** are also considered.

4.2.3 Difficulties and challenges during implementation

A primary challenge during the implementation of collaborative robotic systems is that the thresholds set by the **ISO/TS 15066** are perceived as conservative, as well as not reflective of the current technology's capabilities. They can have a negative impact on the effectiveness of the system, possibly leading to its installation not being considered fiscally sensible. More individual risk assessment is desired, especially for collaborative robotic case studies, as the technology experts report that the current state of the legislation offers little to no room for flexible solutions.

4.3 Worker involvement

As the impulse for a new robotic solution at a workplace can also come from a worker themselves, their involvement in these cases starts right at the idea conception. However, after giving the impulse, a feasibility assessment and the described initial conception steps are performed by experts. Typically, worker involvement during the implementation starts after the concept phase has been successfully completed. During the system's introduction phase to the actual workplace, **workers are routinely involved**. Involving them as early as possible intends to let them get to know the future system and opens up the possibility of collecting **feedback**. Working on the project at this early stage is voluntary. However, the path of early involvement has proven effective in a number of ways. Firstly, it seems to increase the acceptance of the technology once it is fully integrated. Secondly, workers with a high affinity for technology and innovation can be identified, and possibly undergo further training to become the aforementioned key users for robotic systems. The operators of a new system are also present when the system is checked for safety before entering real-time production and can give active feedback and veto rights. However, their involvement does not end with the final roll-out of a robotic solution but continues into the ongoing production. Workers are **trained to optimise production**, hence there is a continuous open feedback system for them to be involved and submit suggestions for changes, optimisation or innovation.

Overall, the role of the worker in the plant is slowly changing. From mostly production work, they move towards becoming key users or receive other specialised training, possibly becoming a system developer, or a problem solver for the company.

Workers who currently work with the robotic systems or cobots so far report both positive and negative experiences. Firstly, robotic systems are not considered unknown or especially new technology at this case study site. The current lightweight robots and therefore automation of manual workstations is new but there is an underlying familiarity with the technology. The positive feedback includes the **reduction of monotonous, undemanding tasks**. Workers who are responsible for maintaining the cobot's system report the job to be **interesting and exciting**. However, the growing presence of robotic systems has also led some workers to express **fear of losing their jobs**. These topics are addressed openly and taken seriously. In a later section, the handling of these issues is examined in greater detail.

4.3.1 Training and worker qualifications

Worker training and education is a major element for the success of technology implementation.[2,3] One of the concerns, when it comes to the automation of tasks through AI-based and robotic systems, is the process of deskilling. Automation like this is generally seen as a starting point for one of three skill developments: **deskilling, reskilling or upskilling**.

The automated task in this case study is a lifting task that does not require a deeply specialised or trained skill that would be lost if a worker does not perform it for a certain amount of time.

All interviewees stressed that training the workers and maintaining their skills and experience within the company is one of the highest priorities. The company aims to **preserve jobs through automation**, not to eliminate them. Hence, they prioritise upskilling and reskilling under the company's core value of **lifelong learning**.

The provided training is tailored to the specific knowledge needed to perform the new or changed task. Training tends to be more intensive for robotic automations. The job groups with the highest need for additional training are the **system maintenance teams**. Continuous training is a prerequisite for the proper maintenance of the robotic systems in the long run. As mentioned above, it is also possible for operators to receive training to obtain qualifications as maintenance personnel. The technology experts are trained by the manufacturer as well as online, both internally and externally. The training is also provided to the previously mentioned 'key users'. These key users are not only experts in a specific technology (like lightweight robotic systems or 3D printers) but also the first point of contact for other workers who bring forward suggestions and requests for new automation solutions at their workplace. Key users can then perform a primary assessment of the suggestion and if deemed feasible, forward it to the appropriate supervisor.

In the broader context, workers can always continue to educate themselves with the support of the company in order to achieve a **higher formal qualification**.

All operators are trained in handling **emergencies and unexpected situations should they arise**. This is a fundamental part of all training provided for a new technology. Every system always has an emergency stop option, in addition to planned stops. While the system is designed to be safe during everyday production, preparing workers for unexpected situations and equipping them with the necessary knowledge and tools to handle these is vital for the overarching safety of the worker.

[2] Waldeck, N. E. (2000). *Advanced manufacturing technologies and workforce development*. Garland Press.

[3] Fraser, K., Harris, K., & Luong, L. (2007). Improving the implementation effectiveness of cellular manufacturing: A comprehensive framework for practitioners. *International Journal of Production Research, 45*(24), 5835-5856. https://doi.org/10.1080/00207540601159516

4.3.2 Feedback system and report handling

The company in this case study values **constructive and continuous feedback** from their workers. Suggestions that are brought forward by workers to change the workplace, by introducing a new cobot or AI-based system, are received and evaluated for their feasibility. Especially during the introduction process, worker feedback is **asked for and encouraged**. Involving the worker early in the process helps to reduce negative feedback in the long run. One way of collecting this feedback is a digital improvement suggestion system, in which each project has its own surveys and feedback box. This also encourages any feedback regarding OSH concerns from the workers.

For more general feedback, the company provides direct persons of contact for workers. These can be their supervisors or representatives of the **workers council**. Should a worker be uncertain who to contact with their specific feedback, there are community networks available to help identify the relevant person.

4.3.3 Level of trust and control

An adequate level of human trust towards the interacting system promotes an appropriate system use,[4,5] **while extreme forms of trust can lead to adverse effects. Excessive trust can lead to automation complacency,[6] whereas insufficient trust may lead to neglect of the technology.** In addition to trusting the system, a worker's level of control can have significant influence on a number of factors.

Named as the **most influential factor** on trust was the **early involvement** of workers during the introduction process. For this case study, this has proven to positively affect acceptance towards the system. Additionally, providing **information early** on and communicating clearly about both the intention of the automation as well as its practical functions is vital. They are aware that trust **develops over time**. After a longer period of use, trust in the machine increases and one can assess it accurately. However, this can also happen with distrust. A valuable lesson learned by the company is that if there is no **transparency** and the workers don't have a **positive attitude**, they might resist change.

Also, a worker's **level of control** can have significant influence on their job satisfaction. Workers are able to exercise control over the robotic systems at different points. For once, workers can have a say in introducing a robot to their workstation. If the assessment of the proposal is positive, this can lead to significant changes for the worker and their surroundings. Beyond that, manual workplaces offer a lot of adaptability to physical needs, like desk height. The process, however, is often not adaptable. A maximum of a few parameters can be adjusted through control units in order to optimise production or address individual needs (for example, standing desk height).

4.3.4 Company culture and structure

The changes that automation can bring to a workplace can impact both company structure and culture and social structures. The extent of this differs from system to system and company to company. Reviewing the company or even only the plant's structure overall, the introduction of the robotic systems, cobots and AGVs has **not changed the formal structure** at hand. Roles have remained largely the same, with only minor changes for key users of the robotic systems. However, the concept is not inherently new.

Regarding innovative systems in general, not only robotic systems, it is part of the company's culture to have cross-site meetings, to exchange experiences, and continuously develop new ideas and be up to date on any relevant changes in other locations.

The process of task automation through robotic systems also falls under the company's core belief of **lifelong learning**. This is ingrained in the company's culture and surfaces in a number of ways, relevant to the automation of tasks through robotic systems. They offer **digital driving licenses** and training courses on the use of robots as well as training and information events for everyone in the plant. Every worker can partake in this training, regardless if they work with an AI or robotic system. The specific location in which the case study is implemented also possesses **a technology training centre**. Here, theoretical and practical training courses are held and selected technologies are on display and can be experienced. This is intentional so that barriers are broken down and everyone is included in the development of the company.

In the larger context of digitalisation, the interviewees observed a shift towards flatter hierarchies in the social interaction between workers. The perception of supervisors and management shifts away from a position of

[4] Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. Human Factors, 39(2), 230-253. https://doi.org/10.1518/001872097778543886

[5] Hancock, P. A., Kessler, T. T., Kaplan, A. D., Brill, J. C., & Szalma, J. L. (2020). Evolving trust in robots: Specification though sequential and comparative meta-analyses. *Human Factors, 63*(7), 1196-1229. https://doi.org/10.1177/0018720820922080

surveillance, towards a perception of them as coaches.

A **unique social dynamic** can be observed towards the robotic systems specifically. There are currently 120 robots in the factory, and an estimated 50% of these robots have their **own individual names**. Reportedly they are sometimes treated as 'robot colleagues' and are actively taken care of by the workers beyond routine maintenance.

Within the scientific literature, concerns of social isolation and job loss are among some named negative impacts of automation. Companies might opt to provide additional support for workers who interact with the system or experience other kinds of concerns. While this factory does not provide specialised support targeted at operators of advanced robotics, they provide a variety of social support structures for all workers. There is social counselling and the workers council dealing with workers' worries and needs. This specifically aims at reducing anxiety and worries, including **fear of job loss**. Fear of job loss reportedly does occur in workers at this production site, and when it is brought up or noticed, it is addressed and worked through. Especially the **logistics department** was affected by this during the introduction of the AGVs. The company offered public 'question and answer' sessions in which everyone could participate. Concerns are brought up and one way of trying to reduce them is conveying what the advantages of the systems are, how jobs are changing and reassuring the workers that the aim is not to eliminate jobs. These measures have had a positive impact on the acceptance of innovative systems in the company.

4.4 Future developments

As one of the motivators to increase robotic digitalisation of the work process is to upkeep and increase competitiveness in the future, the interviewees do confirm that more robotic systems will be introduced at their plant. Innovation and future-oriented decision-making are a high priority for the management personnel in this case study. Looking back at the company's long history of continuous automation and innovation, as well as research, they firmly plan to continue their efforts and developments towards more innovative automation in the future. Some of this will involve robotic solutions in production, as well as AI-based solutions in **production, process planning and office work**. There are plans to introduce more robots, driverless transport systems and advanced manufacturing systems. These systems will be involved in **value-creating activities, logistics processes, ideal just-in-time material processes and customer delivery**, but also **human resources** in the form of software solutions to automate beyond production.

5 OSH impact

The introduction of advanced robotics or AI-based systems can have a wide impact on OSH. It can pose a number of challenges as well as opportunities unique to each case study. Therefore, it is important to identify possible barriers and drivers to consider them in future projects. These new forms of task automation can even lead to changes in the overall OSH management of a company. Through the interviews, a number of these factors for this specific case study have been identified and discussed.

5.1 Challenges

As some AI-based systems and advanced robotics allow highly individualised solutions for a company, they might also face challenges specific to their case study. In addition, a company might also face more universal challenges during or after implementation of the technology. The interviews contained a number of OSH challenges the company had to face, both during the implementation phase as well as in ongoing production.

One phenomenon related to the automation of tasks through AI-based systems can be interpreted as both a challenge and an opportunity. The technology is becoming increasingly customisable. System developers have to decide if a technology should be implemented based on an average worker working with said technology, or if there are groups of workers who need more individualised solutions. The difficulty resides in deciding how to proceed, as both have different outcomes, when it comes to both financial and OSH-related considerations. Weighing the safety advantages of a continuous system and the predictability this brings to a workplace against the possible ergonomic benefits of a custom solution while operating under economic restrictions can be challenging from a management point of view.

5.1.1 Task consolidation

Increased digitisation and, by extension, task automation through advanced robotics has led to **task consolidation** for workers. While in older factory set-ups the worker completed all relevant tasks concerning a workpiece, now they have more and more 'side tasks' in addition to their primary task. Productivity has increased overall, but at the same time, in individual cases, perceived performance pressure has risen.

5.1.2 Qualifications

One challenge reported is the increasing need for workers with **higher qualifications**. While previously there were work activities that could be taught to unqualified staff and learned through minimal training, this is now less possible. While the company provides a variety of training sessions and upskilling opportunities to its workers, they still face a shortage of specialised staff. This holds especially in the area of **electromechanics**, where staff are trained to manage any malfunctioning of the robot.

5.1.3 Cognitive overload

Changes to the work routine are becoming increasingly frequent due to digitalisation. Adapting to these changes, not only in routine, but also by acquiring new skills to work with new equipment can cause **unfavourable mental strain** on workers. While the goal is to make this process as smooth and accessible as possible to all workers, some struggle with it. Reportedly, older workers, and those with a low affinity for technology, experience this more frequently than others.

5.1.4 Fear of job loss

Fear of job loss is a common phenomenon when talking about task automation through robotic systems. As mentioned above, this case study experiences the concern strongly related to the introduction of AGVs. The company has taken several measures to address and reduce this fear in workers, with reportedly good success rates, however they are aware that this issue could resurface when newer technologies are introduced.

5.1.5 Task structure and job content

The introduction of more advanced systems and the reskilling and upskilling necessary to use them successfully has changed task structures for some workers. This changes both job content and the task structures of workers. When it comes to physical products, there tends to be less work done as a team, so one worker tends to work on one product together with a robotic system. The worker is now responsible for handling the system rather than the product. These changes need to be communicated and navigated so that workers are aware of their goals and responsibilities.

Simultaneously, workers also acquire more and **more secondary tasks** instead of a main singular task. While workers in this case study reported it as a positive to have more time to allocate to other tasks, this did not negate the possible risks of disjointed tasks overall. A **decrease in completeness of tasks** can negatively affect a worker's motivation, performance and satisfaction.

5.1.6 Physical risks

Especially since the introduction of lightweight robotic systems that can be used collaboratively, safety has become an increased priority. There is a thorough risk assessment performed concerning extended forces, electricity, squeezing, bumping into the machine and so on. Every risk is classified in the risk assessment and a measure is taken as soon as a criterion is exceeded. This can be a fence, personal protective equipment or an organisational measure in the form of training. Additionally, training is a measure taken to prevent physical harm from occurring, as well as only allowing qualified personnel to work with the system. Nevertheless, there is **always a residual physical risk** when working with **moving machinery**, and robotic systems are no exception to that.

5.1.7 High-risk groups

Working with this collaborative robotic system does not put a specific group at higher risk of injury, stress or strain, under the condition that qualified personnel perform the tasks. As it is a physical task that demands a certain level of manoeuvrability, some workers with specific disabilities (such as blindness, or wheelchair users) generally do not get assigned to work at this specific workstation. However, these cases are treated and **assessed on an individual basis**, in close collaboration with the **company's body for disabled workers**. Individual solutions are considered and, if possible, implemented in a workplace. However, collectively, the company works in close collaboration with their representative body for disabled workers to increase accessibility in the workplace, looking for individual solutions where it seems possible.

While working around heavy machinery, specific risks like magnetic forces and their interaction with **medical equipment** need to be considered. Pacemakers can be impacted under certain circumstances.

5.1.8 Demographic changes

Related to the challenges in the area of worker qualifications, the demographic shift in the workforce also poses a challenge. This expresses itself in the shortage of new workers with the needed qualification. Furthermore, older workers report more challenges adapting to the changes in the workplace and high demand for new skill acquisition. While the company is addressing these issues with training and upskilling, this does not address the underlying societal development.

5.2 Opportunities

The introduction of the technology to the production site also held numerous OSH benefits and opportunities.

5.2.1 Worker qualifications

Upskilling is seen as one of the biggest opportunities for workers. When a cobot is introduced, specialist workers are trained by the integrator to operate the system as well. This enables workers to deal professionally with disruptions during production and learn more about the emerging technology. The training provides them with necessary **skills for future work**.

5.2.2 Physical workload and health

As the worker handles fewer and fewer workpieces directly, but rather supported by a cobot, their **physical workload decreases**. This also holds true for less walking time through the plant when AGVs are involved. Repeated motions and lifting of (heavy) workpieces can lead to strain on joints, if performed over a long period of time. This way, cobots can improve the physical health of workers in the long run. In addition, **accident reduction** is a primary concern of the company, when automating a workplace, which so far has been reported to be successful.

5.2.3 Control over amount of labour

Cycle times and the provision of material have changed in such a way that the robot can, for example, also work overnight or while the workers are on break. This **pre-processed material** is then always available and can be used as needed. This allows workers greater flexibility over their amount of labour and processing speed, as they can plan for the robots' production rate.

5.2.4 Reduced monotony

With robotic systems, there are parallels to classic automation when it comes to reduced monotony. The physically demanding and repetitive or monotonous tasks are automated. This way, the worker can carry out more diverse and **cognitively more interesting tasks**, even if they are related to the assembly of the same workpiece the robotic system is working on, like the assembly of the more complex parts, or quality control.

5.2.5 Task variety

In tandem to reduced monotony, **task variety** also increases. If a worker no longer needs to perform all tasks related to finishing one workpiece, they are free to perform other tasks. This increased task variety for some has expressed itself in increasing their qualifications (for example, becoming a key user) and taking on new responsibilities.

5.2.6 Wellbeing

The interviewees highlighted that any automation introduced to a workplace is done with the goal of increasing workers' wellbeing in mind. The goal is to give workers the opportunity to work somewhere where they **feel comfortable**, that they can set up **according to their needs**, where they can learn, and which promotes the maintenance of physical health and safety. As robotic systems allow a great variety of application and customisation, they have the potential to increase wellbeing for workers.

5.2.7 Social interaction

Increased automation through robotic systems has been attributed to positive social change within the plant. The relationship of workers and supervisors has been described as **less hierarchical**. Supervisors were previously in a more authoritative position and are now seen as coaches for the workers.

5.3 Barriers and drivers

Many companies go through the process of integrating advanced robotics or AI-based systems in their workspace for the first time. The present case study encountered a variety of barriers and drivers throughout this process. Identifying these can help this company as well as others avoid barriers and promote drivers for their process automation.

The factory in this case study already went through the process of integrating both AI-based systems and robotic systems a number of times before. Throughout these experiences, several reoccurring factors were observed.

5.3.1 Barriers

The interviewees identified some barriers at different phases of the task automations. A reoccurring topic was the current standards and legislation in place defining the parameters for robotic systems in the workplace. They are perceived as rigid and not reflecting the current state and capabilities of the technology. They mentioned that there are many guidelines but perceived **lack of expertise** when it comes to robotic systems. A specialist committee on the subject of robotics alone would be desirable, noted one interviewee.

Incorporating state-of-the-art research into standards is challenging. According to the company, this leads to a situation where robotic systems cannot be introduced or be impactful in a meaningful way. They further noted that they perceive some of the standards make the introduction impossible, that they cannot be applied in practice and are not advanced enough for today's technology. Finally, the company notes that the risk assessments for these technologies often lead to safety measures that are so massive they make a project **unfeasible**.

Furthermore, the interviewees noted that sometimes **international** jurisprudence is different from European jurisprudence, and in singular cases it is hard to assess which approach would be superior. Thus, working under a restrictive legal framework hinders innovation and raises the fear of being outperformed or overtaken by a competitor as a company. In addition, there is the fear of losing the position of an innovation hub. The interviewees stated that working safely is a priority, however, there is also the desire to work innovatively.

5.3.2 Drivers

Based on their extensive experience with automation through robotic systems, the company has identified drivers that have benefitted the implementation.

One driver is **involving workers** as early as possible in the implementation process. At this specific plant, there is even what they call a Digi-centre to increase exposure to innovative technology and thereby reduce overall inhibitions towards modern technology. In addition, through open access to information as well as the opportunity to further promote education within the company, it is possible to identify staff with high affinity for technology and assign them roles, like key users. This type of early and extensive worker engagement leads to an increase in acceptance for new systems, and an overall positive attitude towards the subject of task automation.

Secondly, clear and **open communication** between all involved parties has been attributed to preventing as well as solving difficulties during the implementation process. Active encouragement of feedback reduces changes to the system later in the process. Openly and directly handling concerns, such as the fear of job loss, has also been a successful intervention in reducing fears.

In addition, **experience** itself was identified as a driver. The more experience everyone in the process had, from management to workers, the better future projects were handled. This is particularly noticeable on the workers' site, where by now the robotic systems are integrated so deeply into the workplace that they have been given individual names and, to a degree, playful humanisation, by being referred to as 'colleagues'. This positive development is based on positive experiences, which cannot be rushed. However, information exchange and development of case studies can support this process.

5.4 OSH management

New technologies can lead to a change in work procedure. This includes expectations for the technology and subsequent OSH management.

5.4.1 Expectations for OSH

As improving the ergonomic profile of a workplace is already a fundamental goal during automation in this company, the expectations towards OSH are largely congruent with this goal. Regarding the cobot and other robotic systems in production, there are the overarching OSH expectations of reducing injury and long-term strain, increasing wellbeing and providing opportunities for workers to increase their skill set.

5.4.2 Emerging OSH risks and monitoring

The factory in this case study is monitoring cobots and AGVs even after final integration into the production process. In some cases, minor readjustments had to be made to improve the robot's performance or align it more smoothly for the worker with cycle times. In general, the company does continuously monitor for **arising problems and complications**, both OSH- and non-OSH-related, to be able to take **preventive measures** as soon as a problem is detected. Processes addressing this are: workplace inspections that are carried out by **work safety specialists** on a regular basis to identify possible threats, as well as the aforementioned **worker feedback systems**. Furthermore, there are specialised **audits** with a sole focus on workplace safety. When any need for readjustment is brought forward, the necessary steps are taken to ensure the workers' safety. Safety measures taken for robotic systems include **installing more sensors** or introducing **safety barriers**. Every incident or close call is documented and assessed. If the assessment results in a need for action, steps are taken to prevent reoccurrence. Should imminent risk be detected, the cobot is shut down immediately in accordance with the safety measures.

A more unique OSH risk in the context of task automation through collaborative robotic systems is the **fear of job loss**. By now, managers in this factory are aware that workers who do not have experience with robotic systems are more likely to experience this fear, and they try to prevent it by providing ample training as well as open seminars once these fears are expressed.

5.4.3 Communication strategies

The strategies the company uses to communicate internally did not need to be adapted, based on the introduction of cobots or AGVs to the factory site. They continued using the established communication system, including the feedback loop during the technology implementation.

Their communication strategies include that for every new project, a **project lead** is made publicly visible, who can be approached with anything relevant to the project, including OSH concerns. As soon as there is a problem related to safety, it must be reported directly to the manager, who reports it to everyone responsible for addressing the problem. Depending on the type and scope, the response will be timely.

The **health and safety department** must be included for any change to the system, even if it is a minor change. It is checked and if approved, implemented and communicated accordingly. Particular attention is paid to informing the workers when the impulse for change came from them. This helps workers stay aware that their input is heard, valued and implemented.

Any major changes or modification to the system are communicated **directly to the operator**, prior to implementation, but also after testing has been finished. If the change has an impact on occupational safety, this happens as part of a **special instruction**. If there are changes to the workflow or work process, this will be taken into account in the work instructions and the worker will be informed prior to working on the updated system.

On a larger scale, **communication to outward partners** has changed since advanced robotics are increasingly prevalent in factory sites. The technology expert in this case study noted that robotics has inspired the exchange between experts globally. New international teams and communities emerged that did not exist before. This increased exchange is perceived as beneficial for all parties involved.

5.4.4 Organisational and social impact

The organisational impact of the increasing presence of advanced robotics at this factory site is considered comparatively minor. The technology implementation process has not considerably changed, and neither has OSH management or the feedback systems in place. The production process is continuously assessed for optimisation, including the potential for more robotic solutions, but also beyond that. However, there is now a separate **department** that only **installs and adjusts robotic systems**. Other minor organisational structures have also changed. As mentioned before, some workers have been qualified to be **key users** (for example, for robotics or 3D printing) and thus have become points of contact for change suggestions. These key users exist at different levels of the plant and currently number more than 15 people. Digitisation as a whole has also led to an increase in **IT experts** working for the company. Overlapping with possible social impact is the perceived flattening of the hierarchy within the factory site, even though roles were not formally adapted.

No incidences of phenomena like social isolation were reported. Overall, digitalisation has decreased the number of people working **bound to cycle times**. This has resulted in less communal breaks, as they are not predetermined by the cycle times anymore, however, it has also increased workers' control over their time allocation. In total, social interaction between workers did not seem to decrease. Interestingly, the robotic systems have been integrated into the social structure of the worksite, as the workers have given them **individualised names**.

5.4.5 Integration of OSH management

The majority of OSH risk management falls into two categories: machine-based OSH management and social OSH management.

The former includes risk assessments during the planning, execution and running stage of the cobots' implementation. Here, both external safety standards and internal safety standards are consulted. Any classified risk is categorised and addressed accordingly. Any remaining risks are made visible and should new risks be identified they are evaluated to prevent any further impairment of the workers. In the case of acute risk, the system is shut down immediately, in accordance with the set safety standards.

Social OSH management strategies include the education programme, containing clear definitions of who is allowed to interact in which way with the cobot. Additionally, social interventions take place if topics like fear of job loss arise.

The measures the factory currently has in place regarding OSH management were sufficient to address the implementation of lightweight robotic systems without safety barriers, as well as AGVs. Preventive safety procedures as well as managing incidents address OSH-related topics sufficiently. The health and safety department is involved in all changes made to these systems, however, this is also the case for non-robotic systems. An increased focus is placed on technology experts to handle minor incidences, and only **qualified personnel are allocated to work** with the robotic systems.

5.4.6 Need for action

The general desire to **continuously improve communication** between workers and their employer was expressed. Any step taken in that direction, said the interviewees, could reduce overhead and time needed to implement changes. The participation of workers in identifying areas for innovation through robotic systems is described as having possibly even more potential than is currently used.

Beyond internal affairs, external stakeholders were named from whom a need for action was identified. Repeatedly, the **current state of legislation** regarding collaborative robotic systems was brought up by the company. From the company's point of view, it does not reflect the current state of technology sufficiently, and this was directly attributed to the deceleration of innovation.

Need for action was also expressed in relation to larger **research bodies** as well as the technological community overall. More publicly available case studies across different industries, European and non-European, could help identify common problems and help companies keep up with the current innovative trends.

5.4.7 Cybersecurity

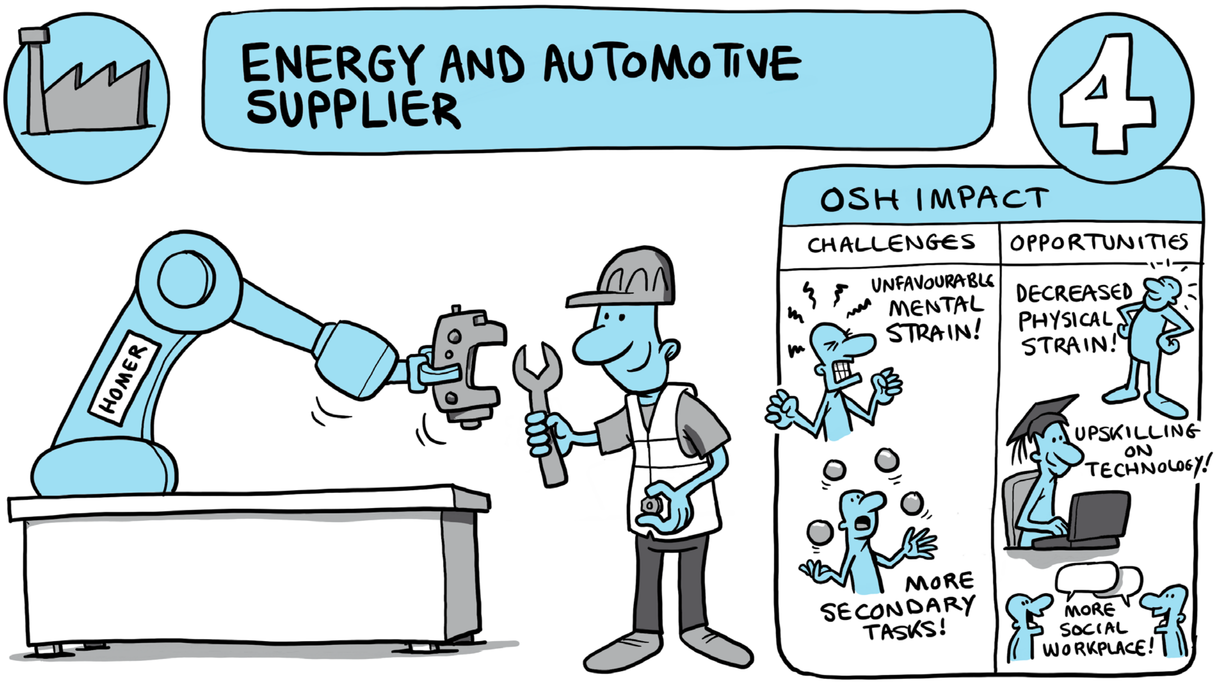
With technology becoming increasingly interconnected and data itself being a resource needed by some AI-based systems to improve their functionality, the topic of cybersecurity becomes prevalent in companies employing these technologies. Some systems require additional safety measures, depending on their use.

Related to this case study, the factory is in line with current consulted standards, guidelines and regulations, regarding both data privacy and cybersecurity. Beyond these, they have also developed their own internal data security concept. This contains detailed guidelines regarding systems that use cameras or collect data. Any collection of person-related data is blocked. Cameras are generally positioned in a way that no worker is recorded, and in the exceptions where this is unavoidable, the worker is informed about it prior to entering that zone.

The cobots and AGVs in this case study, however, do not collect any type of data, nor are they capable of it. Their protection from interference in the form of cyberattacks is covered by the general cybersafety measures taken by the company.

A cartoon-style representation of the system, including some of the challenges and opportunities for OSH is presented in Figure 3.

Figure 3. Multi-axis robots for assembly automation in manufacturing, posing challenges and opportunities for OSH



6 Key takeaways

There are a number of key takeaways from the company's use of advanced robotics in their production site. They confirm that there are physical, psychosocial and organisational benefits from introducing both cobots and AGVs. Reducing forced posture and repetitive strenuous movements has both immediate and long-term **physical health benefits**. The increasingly flexible technology has made adjustable workstations possible. However, this case study also observes a **decrease in completeness** of tasks. These can negatively affect workers' motivation, performance and satisfaction. This process poses a complex challenge. Task automation can enable workers to increase their task variety and reduce monotony. However, this can simultaneously decrease task completeness. A continuous dialogue with workers through a comprehensive feedback and support system can be helpful for a company to assess how the task automation has affected their workers, and enable them to implement countermeasures.

Another important takeaway is the increasing frequency with which workers must acquire new knowledge and skills. Having to adjust their work routines too frequently and needing to acquire too many new skills to perform their job over a short period of time can negatively affect workers' **wellbeing due to mental overload**. Different groups of workers have different affinities for technology and capacity for learning. This case study tries to mediate this effect by **encouraging continuous learning**. Instead of only learning about a technology, once they need to use it, workers have other options to increase their knowledge on AI-based systems and advanced robotics before they specifically need to use the technology. In this way, the training provided to use a new robot is embedded in already existing knowledge. This style of continuous education is accompanied by active **change management**. Informing workers early about changes to their workplace and involving them in the process can increase acceptance and accelerate adjustment periods. Any arising social issues, like growing fear of job loss, are addressed openly and comprehensively for workers, with a focus on the benefits the system will bring them personally.

While the AGVs fully automate the **transportation tasks**, the cobots mainly take on an assisting position in the line of production. When broken down into the most fundamental steps, the cobots can fully automate the task of lifting workpieces. This is, however, part of the larger task of part assembly that still has to be performed by human workers. The cobot reduces physical workload, but the **more cognitively involved task** is still performed by the worker.

Lastly, the three main drivers should be highlighted once again: **involving workers early** and extensively in the implementation process, maintaining **open** and **effective communication** between all parties involved, and the benefit of **experience** with a technology, be it from the company's or workers' side or even learning from an external case study and their experiences.

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