ARTIFICIAL INTELLIGENCE - BASED VEHICULAR AUTOMATION FITTED TO EXCAVATORS TO AUTOMATE TRENCHING (ID6)

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 case 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 present company is a United States-based vehicular automation start-up that develops software and hardware to **automate construction equipment**, such as excavators. Founded in 2016, they are currently categorised as a small company with under 50 workers. They specialise in an aftermarket product that can be added to excavators. Their system adds autonomous robotic capabilities onto existing heavy equipment. The underlying technology functions through a combination of GPS, cameras and **artificial intelligence**.

As a comparatively new start-up, they were founded with a specific goal in mind. Their intention is to **provide robotic solutions that help tackle construction needs in the future**. This is motivated by an increase in modern infrastructure and housing, while simultaneously having a decrease of experienced workers in the industry. They see that autonomous construction robots can accelerate trenching, which aids not only the construction sector itself but also the end users of the constructions. They have successfully implemented their technology on excavators to support construction projects in renewable energy construction sites, like wind and solar, but it has also been used to support trenching for oil and gas pipelines and in agricultural contexts. Furthermore, they postulate that **this innovative technology will revivify younger workers' interest in the industry**.

Another focus they have with their technology is the ease of **physical strain of construction workers**. As one of the most physically demanding job sectors, automation holds the potential to ease physical workload and risk.

3.1 Description of the system

Trenching is a vital step in most construction sites. A trench is a specific type of excavation, characterised by being narrowly dug into the ground and spanning over a specific length in the construction sites. One often sees construction trenches when, for example, repairs on underground electricity lines are performed or as a preparation step for constructing a new structure. Excavators operated by specially trained construction workers currently perform most trenching tasks using manual controls. The **system developed by the start-up automates the trenching process** by providing a multi-part technological solution that can be fitted onto an existing excavator. The system is designed in such a way that it can be retrofitted onto any excavator model and is a means to enable autonomous excavation and earthmoving. Once installed, the system can trench in two modes: fully autonomously or with a human operator still inside, supervising the process. The entire system is composed of four main components: **the external robotic system fitted to the excavator, a specialised operation software**, **robotic operation tools** and a **remote robot monitoring service**. When all are installed, **it transforms excavators into trenching robots**. Additional sensors such as cameras, GPS units and Inertial Measurement Units (IMU)s are mounted at various points on the heavy equipment. However, while the system has the capability to **operate fully autonomously**, it also allows the excavator to switch back to manual operation. The operator can disable the robotic computer from within the excavator or remotely. Furthermore, a human operator must still start the excavator and excavation process before autonomous operation can begin. The operator can switch from autonomous to remote control mode at any time during the trenching process. This is possible through a remote interface that allows operators to control the robotic excavator externally. Beyond switching between autonomous and manual operation, the system also contains additional software for added functionality. Via a custom interface, **a trained operator can manage geo-fences, track production rates, monitor activity and remotely control the robot excavator**. **Operators can also erect digital safety barriers around the system, install both hardwired and wireless emergency stops around the construction site, and create GPS points for the geo-fence, which confines the robotic system to a specified working area in the construction site.**

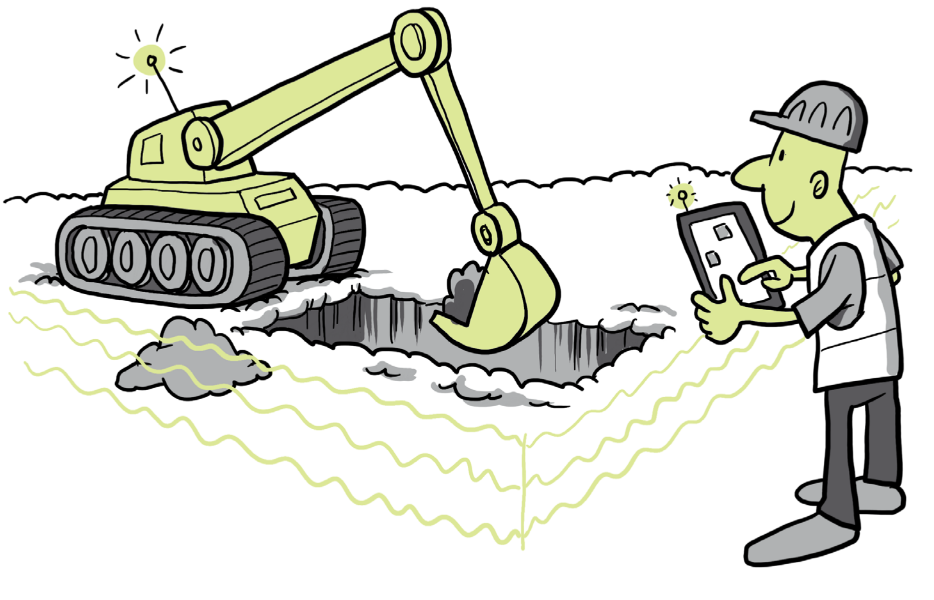
The start-up puts a strong focus on safety within their systems. Excavators are considered heavy machinery; hence, increasing safety measures is fundamental for creating trust in the system. In total, eight safety measures are installed: a video feed of the excavator's work area, a proximity radar, safety alarms, LEDs to indicate the status of operation of the system, a digital geo-fence that confines the system to a designated work site, safety barriers that function as a physical representation of the geo-fence, and hardwired and wireless emergency stops.

Via ongoing video feed analysis, the robotic excavator can also identify and react to obstacles it detects. This **AI-based system classifies the obstacle and displays real-time warnings to the operator**. The video analysis can differentiate between varieties of obstacles, for example, identifying humans when they enter the safety zone, and display notifications on it (for example, 'Pedestrian detected'). In the machine learning data set, which formed the basis for the real-time analysis, the **algorithm** was trained on over **1.7 million example pedestrians**. **This detection and categorisation took less than one second, and the system is automatically paused until it is safe to resume.**

These safety measures are an addition to human-centred safety measures. Operators also contribute a failsafe by managing the equipment operation through the platform and can shut down or switch over to manual operations if needed. Furthermore, only **trained** and **certified operators** are allowed to use the system. However, not only operators are trained by the start-up to know about the functionalities and possible risks of the system, all workers onsite also receive safety instruction to further minimise risk.

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.

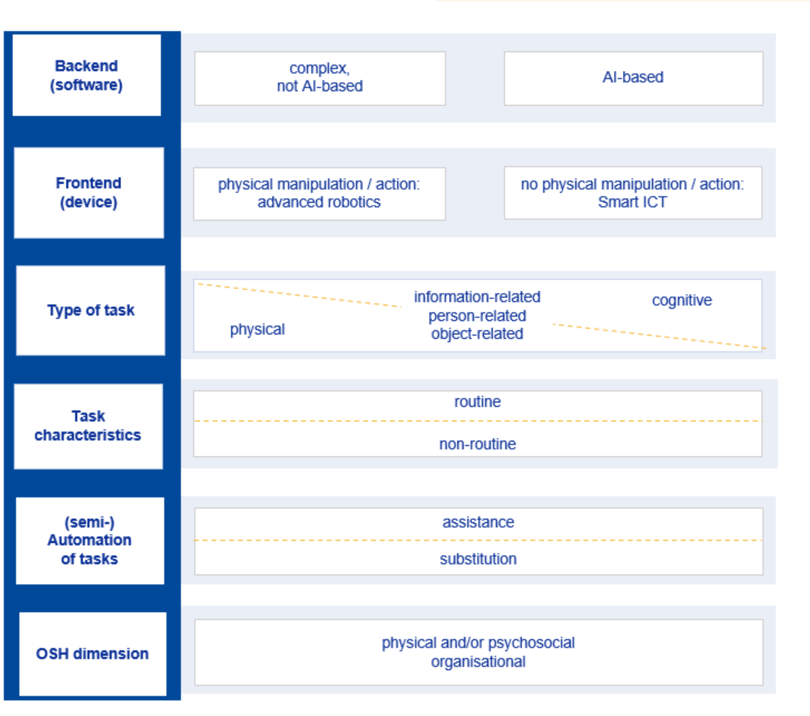
Figure 1. Artificial intelligence - based vehicular automation fitted to excavators to automate trenching



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.

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



[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

The robotic excavator performs a part of the **physical, object-related task** of excavator control in trenching. This is a more complex categorisation. Previously, the operator was not physically moving around but operating the excavator, via levers and a steering system. The physical part of moving earth had already been automated. The robotic system automates the steering process to the degree that once the operator has set where the trench should be dug, the system moves autonomously. Here, its **AI-based software** utilises the input of various sensors (for example, GPS) to orient itself while moving on the construction site. It can be argued that this substitutes a **cognitive, object-related task** as well. However, a trained operator still has to decide the parameters of the trench, and now needs to install additional safety features, like the geo-fence. In addition, the added sensors **fully automate** the **cognitive, information-related task** of **monitoring** the excavation site for obstacles or dangers, if the system runs in autonomous mode. If the operator is supervising the trenching from inside the excavator, they still monitor the surrounding area for obstacles in **tandem with the system**. Hence, the system is capable of both **substituting** human input on this task and also **assisting** if needed.

Once set up, the system is capable of **substituting** the **routine** part of human labour during trenching while the operator now performs monitoring of the system. Additionally, the operator remains in control if they dig the trench themselves or lets the system perform the task autonomously. While the system automates this more complex constellation of tasks, the OSH dimensions it affects are predominantly physical. Naturally, any restructuring of a worksite has organisational antecedents, however, in this case study, they are less impactful on OSH.

The impact of **job content and routine for workers** depends on how the individual company decides to use the robotic excavator. As described above, the system can operate autonomously or in a supervisory mode. Furthermore, operators who remain in the vehicle can manually switch between modes at any given time. Generally, one can say, the amount of time spent on manual trenching is reduced for the operating engineer. However, job content-wise, it is not entirely removed from their needed skill set. If a company decides to run their system at the maximum capacity of autonomy, the workers' routine moves more towards other, excavation-related tasks, such as the installation of shoring. Shoring is an excavation safety procedure used to protect the edges of a trench to prevent cave-in or collapse. Other tasks the operator can be assigned to include the installation of egress ramps, to get in and out of the trench, and the installation of draining systems for the excavation site. Especially in areas with existing utilities, the drainage system should be installed manually. While some excavators are theoretically capable of detecting underground drainage systems, skilled workers can feel the resistance of existing waterlines, and prevent otherwise avoidable damage to existing infrastructure.

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 AI-based robotic excavator.

One motivator to install the robotic excavator system is related to one of the primary customer types the company has. More and more solar parks are being built in the United States. However, these are typically located in big grids in the more rural parts of the United States. To create these solar farms, it is necessary to dig a lot of trenches. The digging process is repetitive and time-consuming work, limiting a high-skilled worker to one location when she/he could be more useful elsewhere. Automating the trenching is intended to allow the operating engineers to perform more high-value tasks.

Furthermore, as the robotic excavation system can perform this task continuously, it can provide higher efficiency in the process. While it is not necessarily operating at a higher speed than a trained operating engineer, it can do so without fatiguing, losing concentration or needing a break. The system allows both private contractors as well as government contractors to execute projects faster, with reduced cost per foot dug, without reducing the quality of work.

Private contractors also see the potential to become more competitive in the long term. The construction sector is experiencing a surge in autonomous solutions, so investing in innovative technology might become necessary to stay competitive.

Lastly, construction sites are known to be dangerous work environments. In the United States, 48% of fatal occupational injuries occurred in transportation and material moving occupations and construction and extraction in 2020.[2]

4.2 Implementation

Before a new technology can be introduced in 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.

4.2.1 Implementation steps

The steps necessary to install the external hardware and software on an existing excavator are very quick and efficient. Depending on the model of the excavator, it can take between two and three hours, possibly longer on older models.

Also, from the end user's side, there are steps needed to implement the system at their worksite, as the system is an upgrade of already existing hardware. It can only operate at sites where excavators were previously in operation. At the same time, introducing the system does not add new requirements to the worksite. The decision process on the end-user side is often driven by the motivation to make their excavation project more cost and time efficient. The fact that the robotic system can be fitted to most of the excavators in the market also reduces the barrier to implement it.

On the end user's side, different prerequisites for the implementation might apply, especially when it is a government-based contract. However, the integrator is not involved in these steps, as they are included once the end user decides to purchase their product. Then they initiate the installation of the system as well as initiate the training programme they provide.

4.2.2 Standards and regulations

To create the technology, a wide range of standards were adhered to. In the creation of the product, all applicable **OSHA guidance** was considered, as well as the **American National Standards Institute's** industry standards for construction systems. When installing the system, there is also a review of the given construction standards performed. The country's states are generally common law jurisdictions, however, a

integrator also wishes to follow **ISO standards**.

4.2.3 Difficulties and challenges during the implementation

Difficulties during the implementation process so far have been few. The conversion process from an ordinary excavator to an automated system typically takes around two to three hours, per machine. On older machines, however, this can take longer and be more labour-intense. This difficulty only occurs on older equipment, not with new excavators.

Next to the technology fit difficulty, there are singular instances where the idea of an **autonomous excavator is met with anything from scepticism to subjective fear**. The company attributes this to the mismatched representation of autonomous systems in media coverage versus the system in real life. It has to be noted that these concerns do seem to dissipate after clients have started working with the system themselves.

4.3 Worker involvement

Worker involvement during the implementation process can contribute to the success of a technology's implementation. Depending on the circumstances, this involvement can start at the design stage, or once training to use the technology starts. While there are external factors that can limit the extent to which workers can be involved, companies seeking to introduce AI-based systems should consider at what stage worker input can be included.

As the system is bought by construction companies from the integrator, there is no worker involvement in the design or implementation process. The installation is also performed by experts from the integrator. Workers get involved at the point of worker training, which is provided by the integrator.

Gaining the certification to use the automated excavator also builds the workers' portfolios and can possibly contribute to future career opportunities.

[2] See: https://www.osha.gov/data/commonstats

4.3.1 Training and worker qualifications

As previously mentioned, worker training and education is a major element for the success of technology implementation.[3,4]

The integrator provides a training programme for their customers. This training programme takes around two to three weeks to complete and is done online or in person. The training includes all relevant information needed to safely operate the automated excavator, both in remote mode and when inside the vehicle. It also includes training on all related functionalities, like the setting of geo-fences, and installation of the wireless emergency stops. When finishing the training successfully, operators receive a certification for this new qualification.

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 company sees the effect their product has as an upskilling effect. Learning how to operate the automated excavator goes beyond their previous task portfolio. It is a technology-centred skill, which needs training to be performed safely and correctly. In addition, there is no concrete risk of deskilling, as the manual mode is still available in the technology and being used by companies. Especially in more complicated excavation sites, like in the inner city where underground infrastructure is installed, a worker's expertise is relied upon to feel for resistances that the excavator might not have picked up upon.

4.3.2 Feedback system and report handling

The integrator welcomes feedback from their customers and clients. So far, the feedback has been very positive. The feedback that they received highlighted that they have achieved their goal of making the process more time and cost efficient (the exact cost-benefit varies based on region).

Should there be any reports of trouble with the system, the integrator does offer a support contact for their customers. So far there have not been any reports that warranted major intervention.

4.3.3 Level of trust and control

An adequate level of human trust towards the interacting system promotes an appropriate system use,[5,6] while extreme forms of trust can lead to adverse effects. Excessive trust can lead to automation complacency.[7] 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.

4.4 Future developments

The company is considered a start-up. They intend to continuously improve their system, for better and safer use. The demand for their system has increased since they came into the market. Future developments of the system include an expansion in safety features, which go beyond the initial trenching task. One example is implementing reminders for safety features (for example, 'If you dig deeper than 5 feet, put in walls, so the trench doesn't collapse when someone enters it').

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.

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

[4] 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

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

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

[7] Parasuraman, R., & Manzey, D. H. (2010). Complacency and bias in human use of automation: An attentional integration. *Human Factors, 52*(3), 381-410. https://doi.org/10.1177/0018720810376055

5.1 Challenges

As advanced robotics allow highly individualised solutions for a company, they might also represent challenges specific to their use. In addition, more universal challenges can emerge, which the company then has to address. The interviews contained a number of OSH challenges the company had to face, both during the implementation phase and in ongoing production.

5.1.1 Mental workload

Operating and overseeing the automated excavator as well as the trenching site can possibly be an increased mental workload for operators. This however is difficult to quantify. During manual trenching, the operator also spends cognitive resources towards monitoring their surroundings. Now they still monitor these factors but have additional input through the system. **The exact cognitive demand also varies, depending on which mode is being used.** In remote mode, operators can focus their complete attention towards supervising the trenching process or disengage as needed. When in the excavator while it is trenching, they still supervise the process and monitor the system from inside.

So, while the cognitive demand may vary, the addition of new monitors and monitoring systems in the work environment can contribute to an increase in cognitive load.

5.2 Opportunities

The introduction of advanced robots to the production site also holds numerous OSH benefits and opportunities.

5.2.1 Worker qualifications

The introduction of these types of automated excavators proves to be a genuine opportunity for workers to be upskilled. They gain additional certifications that can be beneficial for future career developments. Furthermore, the underlying skill needed to operate the excavator and to perform trenching is maintained.

5.2.2 Physical workload and health

Even though this is considered a primarily AI-based case study, as the excavator performs a physical task, the OSH effects and opportunities are also located in the physical realm. Workers operating excavators can experience several benefits to health and safety.

When working from inside an excavator, **the operator is exposed to whole body vibration (WBV)**.[8] WBV is associated with numerous negative health consequences, like neck and back pain, potential cardiovascular diseases, headaches, motion sickness, neuropathies, digestive problems and musculoskeletal disorders.[5] Giving operators the option to perform trenching remotely removes them from the excavator and significantly cuts down on their exposure time to WBV, subsequently reducing the risk of developing associated health problems.

5.2.3 Accident prevention

As mentioned above, the construction sector contains comparatively dangerous work environments. There are safety measures in place to minimise the risk of a manually operated excavator colliding with a worker or workplace material. Inattentiveness, tiredness or workers walking into blind spots can potentially still result in accidents. The automated excavation system provides workers with a heightened level of protection from getting struck by machinery. The camera system that is part of the excavator extension reduces this risk. **This camera system is backed by an AI that was specifically trained to detect pedestrians. If a pedestrian is spotted on camera, the excavation stops until the situation is resolved.** As cameras can be installed so that no blind spots remain, this makes the automated trenching process very safe. So far, the company has not received any reports of workplace accidents related to their technology.

Furthermore, the system has the above-mentioned additional safety layers to ensure maximum safety. All the additional safety measures (for example, geo-fences and light systems) are additional support to ensure that workers are safe while the system is running.

5.3 Barriers and drivers

Many companies go through the process of integrating advanced robotics or AI-based systems into their workspaces for the first time. The present case study encountered a variety of barriers and drivers throughout

[8] Krajnak, K. (2018). Health effects associated with occupational exposure to hand-arm or whole body vibration. *Journal of Toxicology and Environmental Health, Part B, 21*(5), 320-334. https://doi.org.com/10.1080/10937404.2018.1557576

this process. Identifying these can help this company as well as others avoid barriers and promote drivers for their process automation.

5.3.1 Barriers

To this day, the company has not encountered any barriers specifically related to the AI or robotic part of their automated solution. The general **barrier they encounter is an initial mistrust in automated excavators that operate without a visible barrier** (the geo-fence provides a digital barrier, however, the lack of physical representation can be interpreted as a lack of barriers). However, in their experience, as soon as they start working with the system first-hand, and have undergone sufficient training, this mistrust dissipates.

Another barrier they encounter is the current state of official legislation in the United States. As well as ISO and OSHA standards, they reportedly may not provide sufficient guidance for systems with the level of complexity as these automated excavators. The integrator reviews OSHA regulation and guidance, construction standards and other relevant industry standards for their system, to make their system as safe as possible, however, some of these publications are too vague or too old to provide relevant information for their system.

5.3.2 Drivers

A driver in the installation and use of the automated robotic excavator are **workers with a high affinity for technology**. Not only do they display a heightened interest to learn about and understand the system, they also appear to enjoy the use of it more. Noticeably, a group with special affinity for these systems are workers with a gaming affinity.

Another driver for long-term success was the **continuous communication with their customers and operators onsite**. They provide high-value feedback on the systems in field functionality, enabling the integrator to take this feedback into consideration when improving on their designs.

5.4 OSH management

New technology can lead to a change in work procedure. This includes expectations placed on the technology and subsequently OSH management.

5.4.1 Expectations for OSH

The integrator is aware that construction sites are dangerous work environments with heightened potential for physical injury. This is one of the reasons why they implemented so many additional safety layers into their system. By doing so, they ensured that should one system fail to catch a potentially dangerous situation, the others are there to still prevent it. So, the expectation for OSH in relation to their system was very high. In relation to the workplaces in which the system is going to be used, they expected the workers to experience physical health benefits from it, by reducing their exposure to WBV. These expectations have so far been met, and there have been no safety incidents reported so far.

Beyond the expectation that they have for the system in its current state, **the integrator already sees more potential for new OSH features in their technology**. Going beyond the trenching process, they consider implementing safety reminders for tasks related to trenching, like reminders that if a trench is deeper than five feet, the workers need to put up walls so the trench doesn’t collapse when someone enters it. This can potentially decrease trenching fatalities. They expect their system to play an active part in making the workplace safer and see that there still is potential to improve upon.

5.4.2 Emerging OSH risks and monitoring

As mentioned above, the company has a heightened interest in making sure their system is as safe as possible. During everyday operation, OSH risks are monitored via the above-mentioned safety features (for example, geo-fences and cameras). The system comes with an inbuilt ‘health’ system, monitoring the state of the machine. Should this system flag a problem, the machine stops operating. An open dialogue with the contractors that use their system provides them needed insights on possible OSH developments in relation to their system. **Another step they take to stay ahead of emerging OSH risks is frequently consulting other industry best practices and recent scientific publications.**

5.4.3 Communication strategies

The company has a significant interest in communicating with their clients, especially regarding any safety related incidents at the worksite. So far, there have not been any incidents reported to the integrator. They have open communication lines for any feedback their contractors provide and react to each report accordingly.

5.4.4 Organisational and social impact

The organisational impact this system has can vary from trenching project to trenching project. The more of them there are, the larger the impact on possible structures. However, as skilled operators are still needed to both trench and oversee the autonomous trenching process, most organisational structures remain unchanged.

5.4.5 Integration of OSH management

One factor regarding OSH management and the automated trenching system is the way the integrator approaches the worker education on the system. They have noticed that to ensure maximum function from all safety features of their system, it is not only the operators who need to learn about the system. When workers join a worksite, they all have to go through a safety orientation that includes information on the automated excavator, its functionalities and its safety features. That way, everyone gains a deeper understanding of how the system functions, how to behave in what proximity and also to be aware of invisible safety features like the geo-fence.

5.4.6 Need for action

The company sees a need for updated regulations as well as more guidance in the area of OSH since it may take some time to develop legislative provisions that fit modern technologies. In their view, it is an ongoing cycle and that to create informed legislation and guidance, data need to be gathered and analysed. However, depending on how long this process takes, the technology might no longer be the industry standard.

5.4.7 Cybersecurity

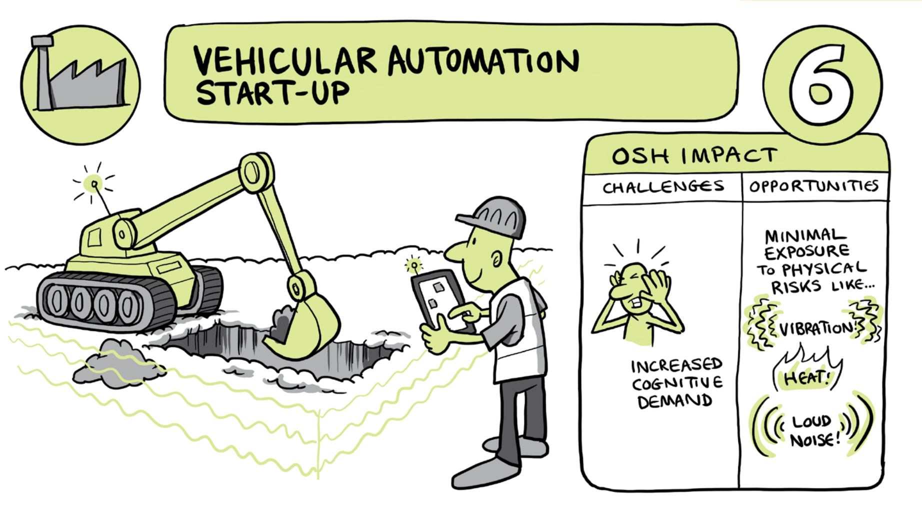
With technology becoming increasingly interconnected and data being a resource needed by some AI-based systems to improve their functionality, the topic of cybersecurity becomes prevalent in companies employing these technologies. The way that cybersecurity is handled at a company level is a key factor in securing the data when it comes to AI-based systems. Some systems require additional safety measures, depending on their use.

Data privacy is highly important to the integrator. Their system complies with all necessary requirements for personal data privacy of the workers. Furthermore, there is no personal data collected by the system. **To make sure that they stay up to date on recent regulations and industry developments, they frequently consult best practices and research publications.**

Cybersecurity is also taken very seriously by the integrator. They frequently discuss the measures they take to protect their system from outside influences internally and adjust, should there be developments regarding technology. Here, they also consult industry best practices and continuously monitor market developments.

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

Figure 3. Vehicular automation fitted to excavators posing challenges and opportunities for OSH



6 Key takeaways

This case study demonstrates that the **borders between advanced robotics and AI-based automation may disappear more in the future**. **An excavator fitted with the robotic extension becomes an autonomous robotic system that fundamentally relies on AI-based technology to operate.** Human operators, however, **stay in control of the system at all times**. This also coincides with a number of subtasks being automated by a system that fundamentally targets one specific main task. However, the start-up has concluded that to automate the physical task of trenching successfully, the robotic excavator needed additional features. **While the excavator could theoretically perform the task of trenching without the added AI-based safety analysis, to be employable on a construction site, this task needed to be automated as well. This highlights the importance of not only considering the main task any system should automate but also to always consider the environment in which it is going to be used and any requirements that come with that.**

The system also demonstrates **flexibility** when it comes to its role in the worker's tasks. The capability to both fully automate a task but also, if needed, assist a worker, and seamlessly switch between operating modes provides operators with a **greater scope of method** on how to approach certain tasks. This touches on two central conversations in the realm of task automation: retention of skills in the workforce and decision authority. Regarding the retention of certain skills in the workforce, this case study demonstrates that a task in general may be automatable, but that the automation might not suffice in all circumstances. So while the basic skill can be automated, the more specialised skill is still needed. This results in workers still training and maintaining the basic skill, as it is the foundation for the more difficult specialised tasks that are likely to take up more time of their work life than prior to the automation. The second part is decision authority. Excavation sites that use this technology decide whether to use automated trenching or not. This decision may fall on the supervisor, or the operator, depending on the specific circumstances. It was the **developers' design choice to include this option to switch modes, which allowed the workers to retain this level of control** over the technology.

During the training of the **AI-based safety analysis**, **the company placed an intentional focus on pedestrian detection**. This came out of the awareness of the potential harm a collision between heavy operating material like an excavator and a human could have. Beyond this, they installed eight additional safety layers. So far, zero incidents of any kind have been reported. While AI is a very powerful tool to support OSH, it is often most effective focusing on a specific kind of application. **Adding further safety measures** in addition to AI ensures that there is no overreliance on a singular system, and it lets workers 'be exposed to fewer safety hazards.

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This case study was commissioned by the European Agency for Safety and Health at Work (EU-OSHA). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect the views of EU-OSHA.