WORKtoZERO
an nsc program

Improving Workplace Safety with Robotics

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National Safety Council

Executive Summary

This white paper explores the use of robotics in environment, health and safety (EHS) applications and how the deployment of such technologies can reduce the risk of serious injuries and fatalities (SIFs). Exploring key use cases, specifically automated facility inspections, confined space entry, moving parts and equipment, machine tending, pick-and-place, hazardous materials handling, and precision welding and cutting, we explore how robotic technology can help eliminate repetitive, manual tasks for human operators and how worker augmentation and task automation can both boost productivity, staff morale and reduce SIFs. Advances in computer vision, data and artificial intelligence have enhanced the capabilities of robotic arms and robotic vehicles, enabling them to perform more complex tasks with greater precision and safety alongside people – but effective implementation is still prohibitively expensive for small organizations needing specialized solutions.

Key Findings:

1. **Robots are available** in various control configurations – remote-controlled, pre-programmed or autonomous – as well as in various forms – autonomous mobile robots (AMRs), automated guided vehicles (AGVs), articulated robots, humanoid robots and collaborative robots (cobots).

2. **AGVs and AMRs** are available as off-the-shelf solutions for small and large industrial warehousing and factory facilities, requiring approximately one week of mapping and route planning before robotics pallets and mobile shelving units become operational.

3. **Remote-controlled robots** offer high-value use cases for confined entry inspections, working from height and hazardous material handling, reducing the risk of human exposure to toxic gases, high temperatures, electric shock hazards and falls from height.

4. **Cobots and robotic arms** are well established for repetitive manual tasks, such as machine tending, parts repositioning and pick-and-place – and implementation and return-on-investment (ROI) can be seen quickly enough for organizations of all sizes. Such deployments can reduce the risk of musculoskeletal disorders from repetitive manual work and allow workers to focus on more varied, complex tasks.

5. **Deployment of safety-related** robotics in more complex and dynamic environments, such as construction, mining and logging require longer development and testing times with the need for advanced computer vision and artificial intelligence technologies – resulting in such use cases being currently available only to large industrial operations.

6. **Pre-built, easy-to-use** robotics hardware and software packages are being continuously developed for additional common safety-related use cases – meaning the real ROI concerning safety will be seen in the near future for both large and small industrial organizations.

Introduction and Background

NSC Work to Zero

Despite concerted efforts to reduce serious injuries and fatalities (SIFs), workplace fatalities have not seen a drastic reduction in the United States. Between 1992 and 2021, the OSHA recordable injury rate dropped from 8.9 injuries per 100 workers to 2.7 injuries per 100 workers, a nearly 70% decrease (Bureau of Labor Statistics, 2022a). In the same period, fatal work injuries only fell by about 15%, from 6,217 fatalities in 1992 to 5,190 in 2021 (BLS, 2022b). Further, between 2020 and 2021, the fatal work injury rate rose from 3.4 to 3.6 per 100,000 full-time equivalent workers. Thus, the expansive efforts by companies to reduce workplace injuries do not seem to translate into impactful reductions in workplace fatalities.

To focus on combatting the lagging decline in workplace fatalities and serious injury events, the National Safety Council (NSC) launched its Work to Zero Initiative in 2019, supported by a grant from the McElhattan Foundation. The end goal of the Work to Zero initiative at NSC is to eliminate workplace fatality risk through the use of technology. Using decades of insight and data, and leveraging the expertise of its membership and network, Work to Zero will identify promising technology innovations geared towards eliminating workplace fatalities within our lifetime.

Digital Technology as an Approach to Reducing Workplace SIF events

In 2020, the Work to Zero initiative released its first white paper detailing the top eighteen hazardous workplace situations (e.g., work at height, machinery operation, confined space entry) and associated situational risks (e.g., falls, struck-by, hazardous gas exposure). The report went further and identified the systemic contributing factors (e.g., lack of training, fatigue and work design) that can exacerbate risk within these hazardous situations. Next, NSC worked with Verdantix researchers to identify over 100 relevant EHS technologies helpful in mitigating both situational and systemic risks and mapped these risks in ways surveyed EHS professionals perceived to be most effective.

The initial Work to Zero report identified several key technologies garnering the most interest and value among the surveyed professionals. In addition, safety leaders within the Campbell Institute at NSC have demonstrated interest in assessing and evaluating certain technologies – such as virtual reality, wearables, sensors and unmanned aerial vehicles (drones). This is one in a series of reports taking a more focused look at specific risks and an associated promising technology.

This report will look at robotics and the use of autonomous mobile robots (AMRs) for reducing injuries and fatalities in the workplace. Additionally, it will explore the identified and proposed benefits of this technology as well as the limitations and risks associated with adoption. Finally, this report will explore the vendor landscape for robotics and AMRs where relevant to workplace safety.

Research Approach

The methodology of this paper consisted of two separate actions:

- **Identification of case studies and suitable applications for robotics and AMRs**
- **Development of a market landscape shortlist of relevant vendors associated with this technology**

Data for this paper came from literature reviews of academic and industry publications, Verdantix reporting, vendor interviews and case studies related to this technology (see References). This paper will focus on aspects of robotics and AMRs allowing workers to perform dangerous tasks remotely, augment workers during manual labor to reduce the risk of injury and automate repetitive physical tasks.

Introduction to Robotics

Robotics describes the field of study focusing on the development and use of robots. Robots are computer-controlled devices capable of precisely handling materials and tools in the place of, or alongside, humans.

Modern robots may include remote-controlled, non-autonomous or computer-controlled motor-driven, pneumatic or hydraulic-actuated grippers attached to a robotic arm, while AMRs may take the form of a compact flatbed device to carry pallets or boxes of goods and parts around a warehouse or factory. Their ability to perform precise, repetitive tasks means they are well-suited to manufacturing applications where round-the-clock, high-volume production is necessary. Re-programmability provides some flexibility to industrial facilities, enabling operators to manage changes in supply, demand, staffing levels and outside forces in real time. As such, robotics is an elemental component of 'Industry 4.0' where sensor-rich environments and internet-of-things (IoT) devices enable highly automated industrial facilities where human-controlled vehicles, their proximity to dangerous machinery – and risk to worker safety – is minimized (Jarota, 2021).

Types of Robots

Robots may be divided into three broad categories based on their method of control:

1. Remote-controlled robots

2. Pre-programmed robots

3. Autonomous robots

1. Remote-Controlled Robots

The simplest control system for robotic systems is a remote operator – a human with a set of levers, buttons and live video feeds – who can orchestrate precise movements of the robot and complete dangerous tasks from a safe distance. For example, explosive ordnance disposal robots provide hazard disposal teams with close-up visibility and physical access for handling dangerous material from a safe distance. Additionally, remote-controlled robots can eliminate hazardous tasks, such as confined space entry inspections.

2. Pre-Programmed Robots

Pre-programmed robots are commonly seen in high-volume manufacturing environments, designed to perform a series of pre-defined movements. For example, an industrial assembly robot for an automotive production line will pick up a panel from a jig and place it onto a car body. Other pre-programmed robots will attach fasteners and weld the panel before moving out of the way and allowing the car body to move on the conveyor belt onto the next stage. Such robots are not designed to account for significant deviation in operating conditions – and instead, rely on simple auto-shutdown fail-safe mechanisms, such as light curtains, to prevent human-machine collision. Autonomous guided robots (AGVs) may also fall into this category since these use magnetic strips fitted to the floors of industrial facilities to navigate.

3. Autonomous Robots

The third category, autonomous robots, is an extension of pre-programmed robots. A task may be explicitly defined, such as the pre-programmed robot picking and placing automotive panels, but the control system may also include cameras and sensors to fine tune the placement of the panel and alert supervisory personnel to alignment defects. Additionally, autonomous mobile robots (AMRs) can navigate to a specified location while avoiding objects and performing course correction in real time (discussed later in this report). Finally, autonomous drones can fly a pre-determined route while avoiding obstacles and adjusting to dynamic wind conditions (see the ***Drones for Working at Height and Confined Space Inspections*** report).

Robots may also be divided into five common configuration categories (Intel, 2022), including:

1. Autonomous Mobile Robots (AMRs)

2. Automated Guided Vehicles (AGVs)

3. Articulated Robots

4. Humanoid Robots

5. Co-Working/Collaborative Robots (Cobots)

1. **Autonomous Mobile Robots (AMRs):** AMRs can perform real-time mapping and navigate through industrial environments without being overseen directly by an operator or being limited to a fixed, predetermined path. With proximity sensors, camera-based computer vision and AI-powered control systems, they can find and pick up objects, perform visual inspections, and move goods and equipment across factories, warehouses and even construction sites. If AMRs encounter new obstacles, such as people, vehicles or boxes, they can immediately re-route to reach their destination. AMRs can travel on wheels for smooth floors or on robotic legs for uneven terrain.

2. **Automated Guided Vehicles (AGVs):** AGVs differ from AMRs, instead relying on magnetic strips placed onto the floor of an industrial facility. These vehicles can perform visual inspections and carry goods and equipment, but without the ability to steer around obstacles or find and pick up objects using computer vision systems. Some include rudimentary collision avoidance features, such as stopping when a proximity threshold is exceeded.

3. **Articulated Robots:** These robots offer dexterity beyond simply carrying goods and equipment, with robotic arms and grippers or other types of effectors to manipulate physical objects using two or more rotary joints. Articulated robots may be fixed to a particular location within an industrial facility or mounted to another vehicle, often used for tasks involving welding, pick-and-place and packaging.

4. Humanoid Robots: These robots mimic the appearance and some of the capabilities of humans, and vary in sophistication from basic head articulation to dextrous robot arms and even walking legs and conversational speech. Such humanoid robots are usually only deployed in entertainment, novelty and research applications, with occasional use in wellness and social care. They do not currently have major use cases within industrial safety.

5. Cobots: These robots are designed to work alongside humans, performing repetitive manual tasks (cobot AMRs) and moving parts from one machine to another (cobot robotic arms) so that workers can continue with more complex and varied jobs. Proximity and strain sensors in the cobot limit the risk of injury to people working around it, minimizing disruption to workplaces otherwise requiring cages, screens and light curtains to prevent human-machine collisions.

Use Cases (Intel, 2022; Control Engineering, 2019; Gould, 2019)

Robotics have several use cases for improving workplace health and safety:

Industrial facility inspection and gauge-reading: Wheeled AMRs can perform light detection and ranging (LiDAR) scans, thermal scans and camera-based inspections of single-story industrial facilities where flooring is free from large debris. For facilities with staircases or rougher terrain – such as construction, mining and logging sites – quadruped inspection robots can still capture round-the-clock data while removing the human worker from on-site hazards.

Confined space inspections: These types of inspections are hazardous for human workers. From 2011 to 2018, 1,030 workers died from occupational injuries involving a confined space (Bureau of Labor Statistics, 2011-2018). These spaces can present high-temperature environments with toxic gases, unsuitable for sustained human work. Remote-controlled robots or AMRs can enter and navigate tighter spaces than human workers, collecting inspection data without risking human life.

Parts, goods and material transportation: These activities are frequently accomplished through forklifts and other vehicles in industrial facilities. AMRs and AGVs can replace humans in these types of repetitive errands and use sensors and computer vision alongside autonomous navigation to minimize the risk of human-machine collisions.

Machine tending, parts repositioning and pick-and-place: Machine tending and parts repositioning by human workers involves physically adjusting or removing production parts or tools and materials from industrial machinery – relying on screens and rudimentary sensors to immobilize heavy pressing equipment or fast-spinning tools to prevent accidental injury. Human operators sometimes bypass such safety mechanisms in the interest of increasing productivity or convenience, increasing the risk of serious injuries and fatalities. By replacing machine tenders with robotic arms and AMRs, these repetitive and high-risk tasks can be eliminated.

Hazardous environment materials handling: Remote-controlled mobile robots equipped with robotic arms offer human operators the ability to handle toxic, high-temperature or explosive material from a safe distance while maintaining dexterity and close-up visuals via multiple cameras.

Precision cutting and welding: Robotic arms offer computer-controlled precision for the repetitive cutting of materials in manufacturing. Additionally, welding robots have seen great success and widespread deployment in welding.

Case Studies

1. **General Electric (GE), a Massachusetts-based multinational conglomerate, saw its Risk Mitigation team searching for a safer replacement for two employees using scissor lifts to open hatches to perform inspections on extraction system ducts. This existing process involved working at significant heights and performing the inspection in confined spaces. GE approached Sarcos Robotics, who provided their mobile Guardian S multi-purpose remote visual inspection robot – capable of performing visual inspections in confined spaces – to survey the whole 853-meter ductwork with high-resolution cameras. In addition to reducing risk to inspection personnel, the robot deployment reduced labor hours from 448 to just 24, and completed the whole inspection in 1.5 days compared to 1.5 weeks previously (Sarcos Robotics, 2022).**

2. **National Grid, an electrical utility in Canada and the Northeastern United States, worked with Boston Dynamics to increase the safety of a regular and critical inspection process for multiple active thyristors in a five-story, football field-sized high-voltage converter station. Due to the extremely hazardous 345,000 to 450,000-volt electric fields, even robotic inspections presented a challenge. The specialized nature of the inspection required remote-control operation and a high-resolution, 30X optical zoom pan/tilt camera with infrared imaging, but National Grid also had to develop an automated system with Boston Dynamics to prevent the operator from getting too close to energized equipment. Partial automation of the inspection rounds led to increased inspection efficiency, eliminated the need to shut down the equipment for inspections and minimized exposure to hazards for workers at the facility (Boston Dynamics, 2021).**

3. **thyssenKrupp Bilstein, an Ohio-based automotive parts manufacturer, deployed cobots by Universal Robotics to automate machine tending, assembly and product inspection to optimize processes and improve the working environment. Since these cobots reduced the workload on existing workers in the potentially hazardous tending of CNCs, punch and forming machines while also eliminating the need to hire additional staff in a tight labor market, the manufacturer saw strong growth in productivity and a 10-14 month ROI (Universal Robots, 2022).**

Vendor Landscape (see References)

Vendors	Headquartered/ Sales Regions	Capabilities
Amazon Robotics	USA / Worldwide	Autonomous warehousing AMRs, robotic arms
Boston Dynamics	USA / Worldwide	Quadruped robot with inspection and mapping accessories, warehouse goods handling AMR with robotic arm and gripper
Caterpillar	USA / Worldwide	Remote-control and autonomous retrofit kits for heavy industrial vehicles
In-Position Technologies	USA / North America	Deployment services for AMRs, AGVs, robotic arms
QinetiQ	UK / Worldwide	Industrial hazardous material handling and military remote-control and autonomous ground-based robots
Sarcos Robotics	USA	Remote dexterity robots, powered exoskeletons, remote-control confined entry robots
Universal Robots	Denmark / North America, South America, Europe, Asia	Easy-to-program robotic arm cobots for automating repetitive packaging, palletizing and machine tending

Benefits of Leveraging Robotics

In the context of workplace health and safety, five main benefits exist for utilizing robotics:

1. Reduce the risk of falls from height

By replacing work-from-height tasks with remote-controlled robots capable of scaling walls or entering confined spaces, injuries related to falls or lifting equipment malfunction can be avoided. Additionally, the low-profile design of specialized inspection robots can allow them to be deployed without requiring equipment shutdown (Gould, 2019).

2. Reduce the risk of musculoskeletal disorders (MSDs)

Since robots are well-suited to performing repetitive, manual tasks, a key benefit to deploying them in manufacturing and logistics environments is their ability to augment or replace human physical labor sometimes associated with MSDs. Robotics can be configured to lift heavier loads than humans, without the associated risk of injury and worker compensation costs (Gould, 2019).

3. Reduce exposure to hazardous substances and environments

Inspections and dextrous work in hot, low-oxygen and toxic environments – or near explosive ordnance – can be completed by remote-control or autonomous robots without associated risks to human health (Verdantix, 2022).

4. Reduce the number of injuries associated with worker fatigue

Worker fatigue is associated with an increased risk of injury – and this can be exacerbated by repetitive, hard manual labor for long hours. Robotics replace such repetitive tasks, allowing human employees to focus on more varied, engaging work and reducing contact with potential hazards (Verdantix, 2022).

5. Improve worker satisfaction

All of the above can result in fewer worker serious injuries and fatalities and improved productivity, which will improve working conditions for existing staff and provide time for more stimulating work – resulting in increased worker satisfaction (Verdantix, 2022).




Risks and Considerations in Using Robotics for Workplace Safety

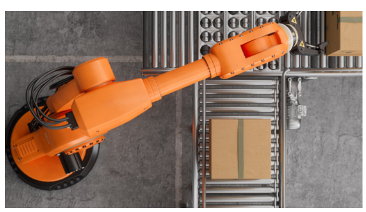
One risk with the use of robotics technology is the high cost of purchase, deployment and the making of adjustments or re-programming. In some cases, expensive add-ons are required to expand capabilities scope and performance, which may become too much for some small organizations to afford. The state of the technology offers a good return on investment for high-volume, highly constrained use cases, such as machine tending and warehouse logistics. However, more autonomous and capable solutions present a price point far too high for smaller industrial operations.

For some, even simple AGV or AMR deployments in smooth-floored warehouses and factories may contribute to disruption to operations. Solutions relying on ultra-wideband (UWB) radio proximity detection may be limited in their ability, such as being unable to track humans in highly metallic environments. Some may instead rely on LiDAR or camera-based computer vision to solve these problems, but this requires extensive and frequent environmental mapping and staff with specialized skills to maintain.

For others, a task may be too complex to solve with current technology. Busy, dynamic environments, such as construction or logging sites present a variety of obstacles, rough terrain, dirt, extreme weather, moving vehicles and workers. Computer vision may be able to recognize some objects, but the number of edge cases to account for can make risk reduction beyond existing levels an impossibility for all but the largest industrial firms. Digital twin simulations operating on the cloud can help accelerate the exploration of edge cases in complex systems (AWS, 2022) and drive real ROI, but such systems still require dedicated development teams and months-long implementation times.

Finally, there is also concern that robotics or other technology may eventually take over for human workers, potentially contributing to widespread unemployment and economic disruption. However, it's important to note automation and robotics also have the potential to improve efficiency, productivity, and safety in many industries (Brosque & Fischer, 2022; Li & Singleton, 2021). While some jobs may become automated, the introduction of new technologies will inevitably also lead to new jobs in fields such as robotics engineering, maintenance and programming. Furthermore, automation can help businesses reduce costs, which can lead to increased investments and the creation of new jobs in other areas (McKinsey, 2018).

There are additional concerns that these benefits will help business owners and shareholders rather than the workers. As such, it's essential to have a proactive approach to addressing the potential consequences of automation, such as retraining and reskilling programs for displaced workers, and ensuring the benefits of automation are shared more equitably across the organization.



Conclusion and Future Direction

Robotics and AMRs are ready for deployment by small and large industrial operations in highly constrained applications, such as machine tending and in-facility goods and parts transportation. However, advanced use cases are not yet available to organizations outside of those with larger budgets and the ability to invest extended periods of time for implementation.

Advances in the manufacture and design of articulated robotic arms, quadrupedal robots, wheeled vehicles and battery technology have reduced the price and increased the viability of robotics for common industrial applications, but levels of intelligence in control systems are still limited. However, the fields of computer vision, data science and artificial intelligence are rapidly accelerating robotics towards a more autonomous future with applications better integrated with complex, dynamic environments and alongside human workers.

Such advances, alongside the availability of pre-built hardware and software packages for ever-expanding applications, will offer high-risk industries robotic replacements at lower price points with better out-of-the-box functionality and ease of programming for staff without specific robotics training – leading to safer and more productive workplaces.

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