WORKtoZERO
an nsc program

Advancing Workplace Safety with Location Geofencing

National Safety Council

Executive Summary

This white paper explores the use of location geofencing in Environment, Health and Safety (EHS) applications and how this technology can reduce the risk of serious injuries, illnesses and fatalities (SIIFs) in the workplace. Often a feature integrated within other commercially available safety technologies, geofencing allows users to establish a "virtual barrier" around a defined area, such as an active construction site or machine operating area.

When an object, such as a worker or equipment, enters or exits the area, a series of predetermined actions or responses will trigger. This can include logging the event for future analysis, alerting workers and supervisors of potential hazards, or disabling machinery or vehicles. While location geofencing has shown promise in EHS applications, concerns regarding data privacy, resource investments and technological limitations have proven to be notable, though navigable, challenges to its widespread adoption.

Key Findings:

- Location geofencing is most often a functionality integrated within other commercially available safety technologies, including proximity sensors, wearables, EHS software or mobile applications, and vehicle or equipment monitoring systems.

- Location geofencing offers several key benefits for workplace safety. By increasing worksite visibility, managers can make data-informed decisions regarding site planning and safety. The technology has also shown promise as an effective risk mitigation tool, alerting ground workers and operators of potential hazards in the area.

- Potential barriers to the widespread adoption of location geofencing include worker concerns regarding data privacy and security, high initial capital and resource investments, and technological limitations.

- For employers interested in deploying geofencing, several factors should be considered, including the nature of the work being performed, the necessity for additional safety features, resource constraints and how the chosen technology will integrate into existing safety devices and systems.

With these benefits and considerations in mind, employers need to adopt location geofencing responsibly. This involves:

- Evaluating the utility and potential barriers to implementation

- Involving workers and key stakeholders early in the pilot and implementation process

- Sharing these experiences with other organizations to foster collective learning

By holistically approaching workplace risks, evaluating integration opportunities within existing safety devices and prioritizing a strong culture of safety, organizations can harness the potential of location geofencing to prevent SIIFs in the workplace while mitigating potential barriers to widespread adoption.

Introduction and Background

Work to Zero

Despite concerted efforts to reduce SIIFs, workplace fatalities have not seen a drastic reduction in the United States. According to the Bureau of Labor Statistics (BLS), between 1992 and 2022, the Occupational Safety and Health Administration (OSHA) recordable injury rate dropped from 8.9 injuries per 100 workers to 2.7 injuries per 100 workers, a nearly 70% decrease (BLS, 2023a). In the same period, fatal work injuries only fell by about 15%, from 6,217 fatalities in 1992 to 5,486 in 2022 (BLS, 2023b). Thus, the expansive efforts by companies to reduce workplace injuries do not seem to translate into impactful reductions in workplace fatalities.

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

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) (Work to Zero, 2020). 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. These technologies fall into one of 11 categories: analytics, content, data management, equipment, exoskeletons, mobile apps, PPE, robotics, sensors/detectors, software and wearables. Visit nsc.org/WorktoZero to access the full report.

Building on the foundational insights from the initial Work to Zero white paper, this report presents an in-depth exploration of location geofencing and its various use cases in safety-sensitive industries such as construction, logging and forestry, manufacturing and utilities. Through a comprehensive literature review, this paper explores the benefits of the technology on workplace safety, highlighting its ability to increase worksite visibility and mitigate potential SIIF hazards. Finally, the potential risks, limitations and barriers to implementation are presented, as well as additional guidance to navigate these challenges.

Research Approach

The methodology of this white paper consisted of two main parts:

1. A comprehensive literature review of academic, industry and grey literature

2. The formation of a dedicated working group comprised of industry professionals

Data for this paper came from literature reviews of academic articles, industry reports and grey literature. A flexible research strategy was employed, utilizing multiple databases, including EBSCO, JSTOR, PsycINFO and Verdantix's research portal. The search strategy was limited to literature published between January 2013 and December 2023. A grey literature search for the same period was conducted using Google Scholar. The search strategy was based on the following iterations of the terms: (Location Geofencing OR Geofencing OR Geofence) AND (Safety OR EHS) AND (Technologies OR Solutions OR Systems).

Additionally, a dedicated workgroup consisting of 15 industry professionals was formed, which provided a platform for members to share their expertise and insights and provide feedback during the research process. This group met three times between October and December 2023 and had the opportunity to review the resulting white paper for accuracy, applicability and relevance.

Location Geofencing for Workplace Safety

What is Geofencing?

Workers in active worksites, regardless of industry or occupation, are often exposed to situations that pose a risk for SIIFs. The dynamic nature of these sites, often a convergence of workers, machinery and vehicles, presents a range of potential hazards. External factors such as noise, passing vehicles or pedestrians, and environmental conditions add additional complexity, making it increasingly difficult for workers to stay alert to their surroundings while also maintaining vital communication with coworkers. Consequently, high-risk areas of a work zone are often controlled via access control solutions, such as physical barriers, badge systems or other monitoring technologies.

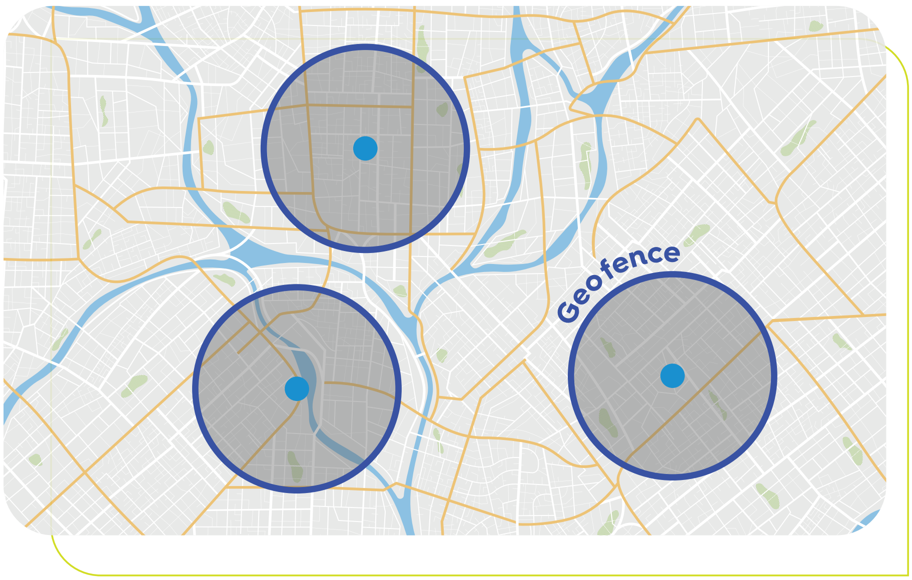
Geofencing leverages location-based data sources, such as the Global Positioning System (GPS), Radio Frequency Identification (RFID), LiDAR (Light Detection and Ranging), Wi-Fi or cellular data to create "virtual barriers" around a geographic area. When a location-enabled device, such as a mobile phone, wearable sensor or in-cab GPS system, crosses the geofenced boundary, a series of predetermined actions or responses will trigger. This can include logging the event for future analysis, alerting workers and supervisors of potential hazards, or disabling machinery or vehicles.

Table 1. Types of Geofences

Types of Geofences		
Type	**Definition**	**Example Use Case**
Static Geofencing	**A geofence that is established around a predefined, fixed area (Namiot, 2013).**	**Monitoring and management of active worksites, hazardous storage areas or live machinery.**
Dynamic Geofencing	**A geofence that can be changed or redrawn based on the location of a moving object or changing data inputs (Namiot, 2013).**	**Monitoring and management of mobile assets, such as fleet management or field workers.**

Geofencing Deployment Options

Location geofencing is typically a feature integrated within other commercially available safety technologies. These systems use a combination of software and accompanying location-enabled hardware, such as proximity sensors, wearables, mobile applications, or vehicle or equipment monitoring systems. Given the wide range of functionalities and capabilities of these technologies, those interested in adopting location geofencing technology should consider factors such as industry type and associated workplace risks, the scalability of the technology, how well it integrates into existing systems and devices, and resource availability.



Proximity sensors, for instance, are most often used to detect the location of nearby objects to prevent collisions or other physical contact. When an object, either a person or equipment, enters the sensor's determined range, the device will record the activity and send data back to the sensor, warning devices or platforms (Work to Zero, 2021). When combined with geofencing, users can establish boundaries around high-hazard or high-traffic areas. When workers or machinery enter the area, custom alerts and notifications can trigger, alerting workers to the potential hazard and serving as a reminder to remain cautious and aware of their surroundings (Work to Zero, 2021). Some proximity sensors can also de-energize or disable nearby machinery or equipment when someone enters the geofenced area, reducing the risk of contact injuries (Blanchard, 2020).

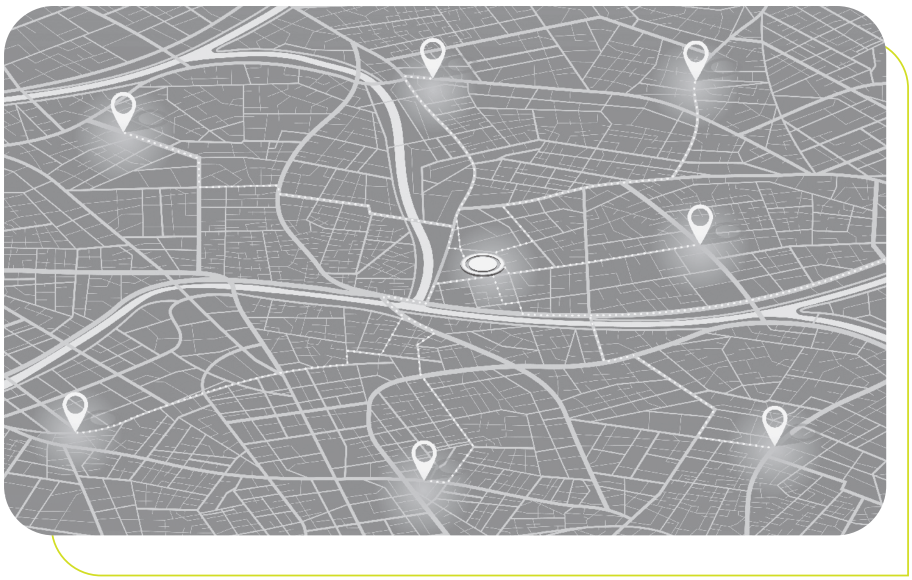
Location geofencing can also be used in conjunction with wearable technologies, such as worker monitoring systems, vital sign monitors, “smart” personal protective equipment, or wearable RFID badges or tags. In practice, workers’ locations are continuously tracked and compared to the boundaries of the geofence (Idris & Pennington, 2023). Alerts, such as push notifications, emails and text messages can be combined with visual, audible and haptic alerts on the device itself (Rahate & Shaikh, 2016). Such alerts can notify workers if they inadvertently stray outside of safe work limits (Connected Places Catapult, 2023), helping them regain situational awareness and move back into a position of safety (Smith, 2022).

These devices can also enable employers to stay connected to their workers, often with two-way communication capabilities. In the event of a workplace incident, emergency, or if working conditions change suddenly, teams can take immediate action, effectively reducing the risk of serious injuries or fatalities (Pedley, 2019). Alternatively, location-enabled mobile devices can also be used as a means for tracking worker location, often more cost-effective and less resource-intensive than wearables or other connected worker devices (Pennington & Bolton, 2019).

Additionally, location geofencing can be combined with fleet or machinery monitoring systems, such as in-cab GPS or telematic systems. This technology leverages real-time data for risk identification, digital sensors for the monitoring of vehicles and environments, and route optimization software (Idris & Pennington, 2023). Combined with geofencing, these devices can provide real-time information such as device altitude, time spent in a certain area or the speed of movement (Smith, 2022). In addition, geofencing can be used to define early warning perimeters for vehicles to indicate their location on active haul roads or around vehicles carrying hazardous materials, helping prevent incidents and coordinate activities in and around a worksite (Zimbelman, Keefe, Strand, Kolden, & Wempe, 2017).

AECOM, a multinational infrastructure consulting firm, implemented a fleet management system that combines location services and driver monitoring solutions to monitor the safety of their operators in real time. The ability to measure and monitor safety is among the greatest benefits of the technology (NSC, 2024). For example, depending on availability, routes might be tightly geofenced, providing supervisors with notifications of off-track vehicles allowing the supervisors to check the live status of workers. If an impact event involving an AECOM fleet vehicle does occur, notifications are immediately sent. Such notifications aid emergency services in providing necessary assistance quickly. Read the full case study at nsc.org/WorktoZero.

Light Detection and Ranging (LiDAR) is also an emerging technology that operates by emitting electromagnetic waves toward a target. The distance between the target and the sensor is calculated based on the time it takes for the emitted light waves to return to the sensor (Benedek et al., 2021). Integration of LiDAR technology into geofencing technologies offers several benefits, including increased accuracy and precision and real-time monitoring capabilities (Benedek et al., 2021). While not yet widely applied, the technology is currently being developed and tested for a variety of safety applications, including autonomous vehicles (Benedek et al., 2021), railway safety (Popa et al., 2022) and mitigating the risk for human-robot interactions (Podgorelec et al., 2023).



Use Cases for Workplace Safety

According to findings from the initial 2020 Work to Zero report, location geofencing was the third most commonly mentioned safety technology for mitigating hazardous workplace situations, namely:

- **Construction and Installation**
- **Logging Equipment Operations**
- **Vehicle-Pedestrian Interactions**
- **Loading and Unloading**
- **Heavy Equipment Operation**

For example, geofencing can be adopted within the construction industry to identify and establish virtual barriers around high-risk or high-traffic areas. When combined with other technologies, such as wearables and proximity sensors, workers can not only be alerted when they enter or exit a geofenced area, but also when they are within an unsafe distance of moving equipment (Idris & Pennington, 2023), mitigating the risk for collisions, caught -in or -between incidents, or contact with equipment.

Location geofencing can also be used to mitigate the hazards associated with roadway construction, which commonly requires workers to conduct their work near ongoing traffic (Gambatese, Lee, & Nnaji, 2017). For example, workers in one study were equipped with wearable "smart vests," which would alert workers via visual, audible and tactile feedback of a potential collision threat or when they approach the edge of the work zone (Vilela, Mollenhauer, White, Vaughan, & Burdisso, 2022). In another application, Network Rail, in collaboration with Connected Places Catapult, identified geofencing as a potential solution to improve trackside working safety. Workers were equipped with wearable safety devices that alerted them when they stepped outside of the safe work zone or got close to hazards such as a live rail or moving equipment (Connected Places Catapult, 2023).

For industries such as logging, forestry or agriculture, geofencing can be used to define and mark boundaries around areas designated for harvesting (Grayson et al., 2015). For example, mobile geofencing can be used to define safe work areas around manual fallers, log loaders and ground-based logging operations (Zimbelman et al., 2017). By equipping workers with personal location devices, machine operators can also be alerted to their presence within the area and make data-informed decisions to avoid potential incidents. Mobile geofences can also be used to define early warning perimeters around log trucks on active haul roads or around other vehicles carrying hazardous materials, helping coordinate activities and prevent collisions (Zimbelman, et al., 2017). In agriculture, particularly in the context of unmanned aircraft systems (UAS) used for precision farming, geofencing has been instrumental in preventing mid-air collisions with general aviation aircraft (Luxhøj, 2015).

Finally, location geofencing might also be a viable solution for managing the risks associated with automated production and transportation environments. By defining boundaries for different zones, such as loading, unloading and transportation zones, geofencing can serve as a potential countermeasure to reduce risk (Javed et al., 2020). Geofencing in manufacturing, for example, can be used to delineate pedestrian zones, restrict access to hazardous areas, and even de-energize or deactivate nearby machines or vehicles (Blanchard, 2020). The use of wearables with location geofencing can facilitate safety alerting and mustering and enables employees to send SOS alerts to indicate an emergency or if assistance is needed at their location (Alexander, 2021). Workers in production settings may also benefit from proximity-based learning applications of the technology, where supplemental resources or training (e.g., documents, videos, microlearning modules) can be delivered to workers when they enter a particular area of the worksite, serving as a potential problem-solving or training reinforcement tool (Balaraju, 2020).

Market Overview

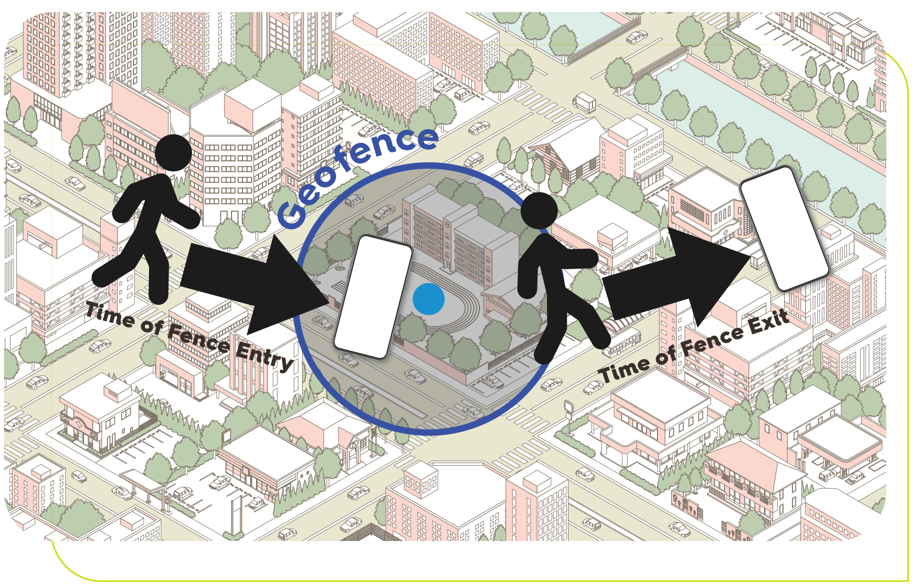
The location geofencing market encompasses a wide range of use cases, from location-based marketing and asset tracking to indoor navigation services or child safety. According to market research company Technavio (2022), the geofencing market, in general, is estimated to grow at a compound annual growth rate (CAGR) of 22.35% between 2022 and 2027, or about $3 billion globally. Notably, North America is estimated to contribute 37% to the growth of the global market, with transportation and logistics being major contributors. While estimating the anticipated growth of location geofencing specifically for safety applications can be challenging, market estimations for other related safety technologies provide evidence of an increase in the adoption of such location geofencing-enabled devices in the future.

Benefits, Limitations and Considerations

Benefits of Leveraging Location Geofencing for Workplace Safety

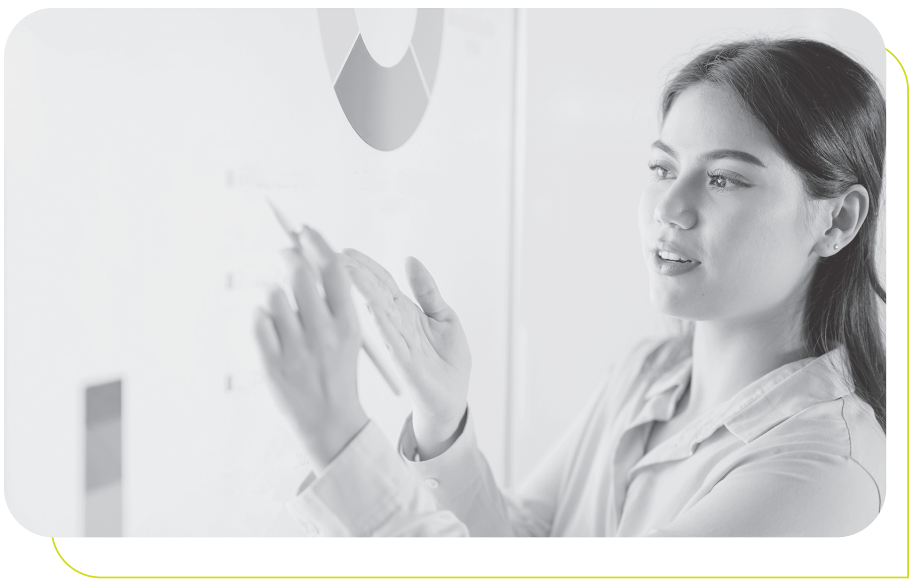
A primary benefit of location geofencing is its ability to immediately identify and alert workers of potential hazards before an incident occurs. For instance, if a worker inadvertently walks into a high-risk area, a series of alerts can help workers regain their situational awareness and move back into a place of safety (Smith, 2022). Machine operators can also receive vital notifications if a breach of geofence is detected, allowing them to make informed decisions based on the locations of workers or other equipment in the area (Wempe & Keefe, 2017). Notably, the cadence and delivery of these notifications are often customizable depending on the needs of the employer. For example, periodic geofencing can be used to monitor movement in certain areas only during certain periods, while conditional geofencing allows users to calibrate certain parameters, such as alerting only when a certain number of vehicles or workers enter an area. (Javed, et al., 2020). Notifications can also be delivered in various forms, such as emails, push notifications, phone calls, software alerts or other means of communication (Rahate & Shaikh, 2016).

Employers can also gain greater visibility into worksites using the technology, receiving valuable data such as who, or what, has entered or left a geofenced area, as well as data on device altitude and position, movement speed or time spent in a particular location (Smith, 2022). With the ability of the technology to enable real-time monitoring of workers, vehicles or equipment, site managers can make data-informed decisions regarding site planning and safety. For example, users can also restrict access to pedestrian zones and walkways, specify keep-out zones, and restrict truck or equipment access into designated areas (Blanchard, 2020).



By increasing visibility, employers may also benefit from streamlined worksite monitoring and management. The use of automated alerts reduces the reliance on continuous human supervision or extensive video surveillance for tracking worker locations, allowing site managers to redirect their focus to other critical safety aspects within the worksite, optimizing both resource allocation and overall safety management. Additionally, by establishing virtual barriers, geofencing may also eliminate or limit the need for physical barriers to fence off hazardous areas, making projects quicker and easier to set up in certain scenarios (Smith, 2022).

Finally, employers should consider the additional productivity or operational benefits associated with location geofencing. For example, the technology can be used to monitor workflows (Javed et al., 2020), increase operational efficiency (Wempe & Keefe, 2017) or track assets (Smith, 2022). These additional use cases can increase the return on investment (ROI) and facilitate the integration of the technology into existing workflows.



Barriers and Considerations for Implementation

While location geofencing can be a valuable tool for workplace safety, employers need to understand the potential barriers and technological limitations that may prevent its widespread adoption. A primary limitation associated with geofencing is that it mitigates, but does not eliminate, workplace hazards. Therefore, if elimination or substitution is not feasible, deployment of this technology should be combined with other administrative and engineering controls, such as safety training, physical barriers or lockout tagout procedures, allowing for a more comprehensive approach to site safety.

Technological limitations associated with location geofencing also exist that should be acknowledged. Research has shown several factors can impact the accuracy of geofence alerts, including the speed of the tracked object, the angle of intersection with the geofence and the distance from the receiver (Grayson, et al., 2015). Applications of geofencing within logging operations have also demonstrated that certain positioning, such as under mature forestry canopy or other terrain effects, can impact the accuracy of the technology (Wempe & Keefe, 2017). Therefore, it is recommended employers adopt a balanced and realistic approach toward adopting these types of location-based services, where these solutions are used proportionally to accuracy limitations (Wempe & Keefe, 2017). During the procurement process, employers should inquire about the accuracy and reliability of the chosen system in various conditions, its compatibility with existing systems and the ability to scale the technology in the future.

Privacy (Wempe, Keefe, Newman, & Paveglio, 2019) and security concerns (Technavio, 2022) are also potential barriers to the widespread adoption of location-based devices, such as geofencing. In a survey of 280 loggers attending a professional development workshop, roughly 19% of workers and 33% of supervisors indicated they had privacy concerns associated with real-time location sharing (Wempe, Keefe, Newman, & Paveglio, 2019). Similarly, in a survey of more than 4,300 construction workers, the most prevalent concerns regarding the adoption of safety monitoring devices were that their data could end up in the wrong hands, their employer could obtain private or sensitive information or their employer could use this data against them in the future (Haikio, Kallio, Makela, & Keranen, 2020).

To ease worker concerns, it is recommended employers draft strong data privacy policies that outline what data is being collected, how it will be used, where it is stored and how it will be encrypted. It is also recommended workers be involved early in the pilot and adoption process. While earning worker buy-in can be a potentially prolonged process, educating workers on the benefits of the technology, its functionalities and its limitations is important. Transparency regarding how data will be used is critical to increasing user acceptance of safety technology (Ferguson, 2022).

Finally, employers should consider the capital and resource investments necessary to successfully pilot, adopt and scale technology. According to Technavio (2022), the adoption of geofencing solutions can be cost-prohibitive due to hardware requirements. The complexity of deployment, especially regarding their integration with existing IT infrastructure, can further strain organizational resources. Employers should also bear in mind the need for workers to carry secondary devices (Wempe, Keefe, Newman, & Paveglio, 2019) or the resulting drain in battery life from leveraging mobile applications (Namiot, 2013). In occupations where workers carry multiple tools or equipment, adding another device might be impractical. Therefore, employers should explore the possibility of integrating geofencing capabilities into existing devices to streamline the process of adopting and scaling the technology.

Conclusions and Future Direction

Workers on active worksites are often exposed to situations that pose a risk for SIIFs, such as vehicle-pedestrian interactions, caught -in or -between incidents, and chemical or electrical exposure. By enabling users to create a virtual barrier around a particular area, location geofencing can mitigate potential risks by increasing visibility into the worksite, alerting workers and machine operators of potential hazards, and keeping employers connected with lone, isolated or mobile employees. In general, the adoption of location geofencing has been most common within safety-sensitive industries, such as construction (Connected Places Catapult, 2023; Vilela et al., 2020), logging and forestry

(Wempe & Keefe, 2017; Zimbelman et al., 2017), agriculture (Grayson et al., 2015) and manufacturing environments (Alexander, 2021; Blanchard, 2020). However, barriers to widespread adoption include cost and resource investments, worker concerns over data privacy and security, and technological limitations.

Given the market for geofencing is anticipated to grow (Technavio, 2020), there is an increasing need for research and evaluation in the area. More robust studies are needed to better understand the effectiveness of its application in workplace safety, including the technological considerations and limitations. The sharing of use cases and case studies is also necessary to demonstrate the benefits, limitations and considerations for adopting location geofencing in the workplace. Finally, it is recommended that the ethical use of technology in the workplace, particularly regarding the collection and use of personal data, is an ongoing conversation between employers, workers, labor unions and industry leaders to promote transparency, safeguard worker privacy rights and foster a culture based on trust and accountability.

With these benefits and considerations in mind, employers need to adopt location geofencing responsibly. This involves combining the technology with other controls, such as employee training, physical barriers or lockout tagout procedures to ensure a holistic approach to controlling for workplace risks. Small-scale pilots can be an effective way of assessing the impacts, costs and potential barriers to widescale adoption while keeping initial costs relatively low.

Employers are also encouraged to share these experiences and best practices to facilitate collective learning and continuous improvement. By holistically approaching workplace risks, evaluating integration opportunities with existing safety devices and prioritizing a strong culture of safety, organizations can harness the potential of location geofencing to prevent SIIFs in the workplace while mitigating potential barriers to widespread adoption.

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