Will the Autonomous Mobile Robots Revolution Endanger Us?

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

In 2022, 3.8% of warehouse workers were estimated to have had serious injuries while on the clock (Costa, 2024). This places warehouse workers as the highest estimated rate of serious injury among all private sectors (Costa, 2024). A major innovation occurring in warehouses recently is the introduction of robots. Specifically, the usage of autonomous mobile robots (AMRs) has taken off in an effort to improve company profits. Amazon currently utilizes over 750,000 robots across all of its warehouses globally (Dresser, 2023). This paper demonstrates how the increase in collaborative robots in industrial settings affect workers' productivity and safety in these environments.

The usage of AMRs has increased in many industries over the past decade. A prominent example is self-driving cars. Companies like Tesla and Waymo have had a lot of success on the consumer and service aspects of self-driving vehicles. On the other hand, companies like Cruise have gone down due to failures in their safety systems resulting in dangerous behavior (Naughton, 2024). Studying the variability of these autonomous vehicles and their reliability and impact on human safety is imperative to guarantee safety in a technology-focused future. The inherent safety concerns with AMRs and their interaction with humans in warehouse spaces poses an important question about whether or not their utility outweighs their potential harm. That is, how does the increase in collaborative robots in industrial settings affect workers' productivity and safety in these environments? Using the framework described by Susan Leigh Star in her 1999 article *The Ethnography of Infrastructure*, this paper analyzes the integration of these AMRs into human-based industrial settings.

Research Methods

This research studies the safety and productivity impact of AMRs. In particular, it investigates a correlation between the growth in collaborative robots in industrial settings and workers' productivity and safety in these environments. I analyze historical data regarding injury rates and worker output per-capita before and after the integration of AMRs to get metrics on safety and productivity improvement. Metrics gathered include per-capita worker injury rate, per-capita worker productivity rate, overall cost of production, and general worker mental health statistics in warehouses with and without AMRs. The reports used are published by the Occupational Safety and Health Administration (OSHA) and the National Safety Council (NSC). I also gathered anecdotal evidence of the effect of AMRs on warehouse productivity and worker safety in the form of statements by workers, warehouse supervisors, and CEOs. Keywords to guide my search included "automation," "robots," "warehouses," and "safety." Through this evidence, I demonstrate the impact of the integration of AMRs on warehouse safety and efficiency.

Background Information

Many improvements have been made to warehouses to help improve worker safety and productivity. Allowing for flexible work hours and switching from paper to personal digital assistants (PDAs) has boosted worker mental health by over 40% (Dade, 2025). Additionally, to assist this effort, the Occupational Safety and Health Administration (OSHA) has created several regulations on required practices and procedures for workers and businesses to follow. For example, the Warehouse Worker Protection Act passed in May 2024 increased OSHA training standards for warehouse workers operating heavy machinery and improved the protocols for injured warehouse workers (Text - S.4260 - 118th, 2024).lacks any specific AMRs, and instead defaults to those pres OSHA also developed a technical manual describing industrial robot systems and outlining some safety factors, however none of these are specific to AMRs and are instead general to all industrial robots (Occupational Safety and Health Administration, 2025). Additionally, while organizations such as National Institute of Occupational Safety and Hazard (NIOSH) describe recommendations for AMR design to help prevent injuries, these are not strict regulations (Center for Disease Control and Prevention, 2014).

AMR safety is difficult to govern because their design and operation varies significantly based on the needs and context of each application. Even within a single warehouse, a variety of different AMRs can be used. For example, in Amazon warehouses, their Proteus robot is designed for moving carts of packages, whereas the Sequoia robot is optimized for product storage (Greenawalt, 2024). Additionally, there is great variety in the control algorithms that these robots use to dictate their movements. Many of these algorithms may be based on machine learning, a method of control that is able to learn from continuous iterations, either in simulation or in real-world testing (Rudin & Radin, 2019). However, machine learning is oftentimes looked down upon for safety-critical situations due to its lack of transparency (Adebe, 2023). Because it acts as a black box, it may be difficult to analyze or guarantee individual decisions.

A key factor to all machine learning algorithms is their simulation and training data. Most algorithms will only work properly if their training data is up-to-par. However, while simulation allows for robots to gain some learning capability and understanding, there will always exist a sim-to-real gap, since no simulator can predict a perfect model of the actual environment (Trentsios et al., 2022). AMR performance in the real-world improves over time due to their ability to gather real-world data, allowing developers to improve the models and fix any bugs the robots run into. Thus, some risk needs to be taken when the robots are first deployed with the knowledge that over time these robots will generate more data that the rest of the robots can use to improve.

However, issues arise around the training data pipeline company trust because while machine learning algorithms and models may be open-sourced, the actual training data is often not due to privacy concerns, making it difficult for third parties to analyze and validate the robot's software. According to the UK's Information Commissioner Office (ICO), the access to CCTV footage in warehouses is limited to a few, trustworthy people. Additionally, policies like the Data Processing Agreement (DPA) limit data storage length, requiring the National ANPR Data Center to perform 6.7 billion data deletions annually (Bamford, 2015). These limitations on data access and retention clash with the concept of open source datasets, which are used to share data across the world and provide external developers the opportunity to help improve these machine learning models.

Ethnography of Infrastructure and AMRs

Susan Leigh Star's *Ethnography of Infrastructure* (1999) provides a compelling lens for analyzing the impact of AMRs on warehouse workers' safety and productivity. Three core aspects of the framework are that technology is built around an existing base infrastructure, should follow existing standards, and should be visible when broken. Using these concepts, Star's framework can be used to analyze the integration of AMRs into human-based industrial settings.

Scaife utilizes Star's framework in his 2023 paper to analyze AI accountability when making erroneous decisions (Scaife, 2023). In particular, he uses three tactics that Star describes that are crucial to studying infrastructure: identifying the master and non-master narratives, analyzing what occurs when the infrastructure breaks down, and determining paradoxes, which are small changes that cause significant technological challenges for the user. Using these techniques, Scaife analyzes several cases where AI has gone rogue or has been forced to make a difficult decision. Among these, he investigates the case of autonomous vehicles, which is tangent to my analysis of autonomous mobile robots. His research leads him to claim that AI models need to be held accountable as their own entity, acting as if they were a separate person. This conclusion is in consensus with other people (Stevens, 2023) who have analyzed the integration of AMRs into warehouse infrastructure.

However, there exist counter-arguments among authors stating that AI policy is not as necessary as it seems (Taylor, 2023). They argue that such policies would slow down development of novel models and technologies. Additionally, since systems are always evolving, it would be difficult to maintain policies that are able to keep up with the technology. These arguments are similar to those posed regarding policies for AMRs in warehouses. However, as Scaife mentions, technology is never guaranteed to mature, and pushing off the policy could make it more difficult to regulate in the long-term. In general, most authors are in agreement that Star's framework is crucial to analyzing the impact of AMRs on existing warehouse safety and productivity.

Results and Discussion

The results of this study provide empirical insights into the effects of AMRs on worker safety and productivity in industrial environments. By analyzing historical data on injury rates and worker output before and after AMR integration, key trends emerge regarding the role of automation in shaping workplace dynamics. The findings indicate that AMRs have increased the production output capabilities of warehouses. However, they have also resulted in an increase in injury rate among warehouse workers and have also led to overworking. The increased usage of AMRs also causes many warehouse workers to fear losing their job or getting injured from the robot, increasing stress and decreasing satisfaction in the job environment. The following section presents these findings, drawing from research studies and anecdotal evidence to provide an assessment of AMRs' impact on warehouse safety and efficiency.

Human-Centered Infrastructure

Many warehouses were built decades prior to the new robotic revolution, and thus were not built with robots in mind. Because of this, automation and robotic systems have been added to the existing infrastructure of warehouses, an infrastructure that was initially developed for humans. This relates to one of Star's core principles of infrastructure, which states that new infrastructure is built around an existing base infrastructure.

The National Safety Council (NSC) investigated the safety impact that three different types of robots had on the workplace: remote-controlled robots, pre-programmed robots, and autonomous robots (2023). The use cases for the robots that they investigated involve confined space inspection, material and goods transportation, hazardous material handling, parts repositioning, and precision cutting and welding. The NSC's study focused on three case studies, all of which supported the benefits of utilizing autonomous robots in the workplace. Both General Electric and National Grid utilized autonomous mobile robots for visual inspection, replacing jobs requiring the use of dangerous equipment or hazardous materials. These companies also saw an increase in productivity, with General Electric's labor hours per-inspection reducing from 448 to just 24.

In addition to raw statistics, the perspective of the workers themselves is important to consider. A research study conducted by the Oxford Internet Institute and the Global Partnership on Artificial Intelligence interviewed various workers at Amazon fulfillment centers about their thoughts on the additions of the new robots (Fairwork, 2024). Workers told the researchers that the company has increased work pace to hit ever-increasing performance targets. However, the financial gains that came from this increased productivity were not redistributed to workers in the form of increased pay. Thus, workers feel that they have been forced to work in demoralizing, stressful, and dangerous conditions for 60+ hour weeks to make ends meet (Fairwork, 2024). This evidence points to the fact that while companies have focused on adding AMRs to their warehouse environment, they have not considered entirely the human aspect of these additions and how the robots may impact existing warehouse dynamics.

AMRs have also instilled a major long-term fear in warehouse workers: the potential to lose their jobs to robots. A research study found that 42% of negative responses that workers had with regard to robots were related to the fear of job loss (Lui et al., 2022). According to workers, the lack of fair representation on the use of AI and robotics has led to an increase in this fear as more and more warehouses integrate AMRs (Fairwork, 2024). Dixon, for example, was left largely unable to work due to her injuries, and is now struggling to land a new job with fear of losing her home (Anway, 2022). Another employee mentioned that there are "a lot of people at Amazon who are on light duty - that means they can't lift heavy things - but now obviously with automated picking coming in, that is taking them out of a job (Fairwork, 2024)."

Workplace Safety Standards

Another crucial aspect of Star's Ethnography of Infrastructure is that new infrastructure should follow existing standards. Many warehouses were built decades prior to the new robotic revolution, and thus were not built with robots in mind. Because of this, automation and robotic systems have been added to the existing infrastructure of warehouses, an infrastructure that was initially developed for humans. For warehouses, the key standards that affect workers boil down to safety and productivity. That is, the addition of robots should not require negotiation with existing standards of safety or productivity in warehouses.

In 2023, Scott Dresser, VP of Amazon, introduced their new cutting-edge AMR systems, Sequoia and Digit. They worked together to enhance inventory management, speed up order processing, and assist in repetitive tasks like navigating tight spaces. These AMRs, among their fleet of 750,000 robots, are intended to decrease injury risk and help with physically demanding jobs. Dresser claims that these robots will create new job opportunities for employees, improve operational efficiency, and reduce injuries (2023). However, the statistics show a different story. In 2020, Will Evans, a journalist, calculated the annual injury rates across more than 150 Amazon warehouses between 2016 and 2019. The average annual serious injury rate at Amazon warehouses increased from 5.7 to 7.7 serious injuries per 100 workers in this span, an increase of 33% and nearly double the industry standard of 3.9 injuries per 100 workers. By isolating the injury rates per warehouse, his study concluded that the rate of serious injuries from 2016 to 2019 was 50% higher in warehouses with AMRs (Evans, 2020). In the same time period, the robots Amazon deployed were becoming stronger, faster, and more efficient. However, colliding with stronger and faster robots is much more likely to result in injury than slow, weak ones. Additionally, many Amazon workers reported that the increase in efficiency, and thus productivity expectations, forced workers to work faster and longer hours, straining their body in order to avoid being the bottleneck (Elew & Oh, 2020).

These injuries also stem from lack of federal regulation enforcing. OSHA has created technical reports describing best practices for deploying, operating, and interacting with AMRs in warehouses (U.S. Department of Labor, 2022). However, while the regulations are in place, there seems to be a lack of enforcement. A 2023 report by The U.S. Department of Labor's Office of Inspector General (OIG) found that the number of warehouse worker injuries nearly doubled from 42,500 in 2016 to 80,500 in 2021. Despite this stark increase in injuries, OSHA failed to conduct adequate inspections, as only 4.1% of warehouses were inspected annually, with most inspections initiated by complaints rather than proactive safety measures. Placing novel AMR technology in an unregulated environment can result in dangerous working conditions for employees.

An example of this is Candace Dixon, a stower at an Amazon warehouse whose back was severely injured from lifting 100,000 boxes over the span of 2 months (Anway, 2022). Her doctor attributed the injuries 100% to her workplace. Her job was to unbox products, place them on robots for transportation, and scan their new locations. To hit her quota, she needed to scan a new item every 11 seconds, leaving no time to waste. In an effort to increase productivity with the deployments of robots, Amazon management has also installed various monitoring technology, including automated camera surveillance and countdown timers between each scan to detect if any microbreaks were taken (Anway, 2022).

Many proponents of the warehouse robotic revolution point to the fact that workers in non-robotic facilities walk 10-20 miles per day to transport items. However, even this optimization has drawbacks, as removing this transportation time allows management to force workers to perform quick repetitive movements for long periods of time. According to the New York Times, this has resulted in a 3-4x increase in worker quota for various tasks (Scheiber, 2019). This focus on product output instead of worker safety and well-being plays a key factor in the sharp increase in worker injuries. In his 2020 letter to the shareholders, Jeff Bezos mentioned the launch of a program WorkingWell, which aimed to coach employees on body mechanics and proactive wellness. While similar solutions could help diminish the increase in injury rate, it does not address the underlying problem of being a profit-first company and overloading workers with impossible quotas. One worker interviewed about the wellness programs mentioned that "[it's] still, repetitive movements – as I said, people are doing 400 packs per hour – is going to, you know, after a while, you're going to start feeling it (Fairwork, 2024)."

Inadequate Worker Training

Another crucial aspect of novel technology is the knowledge that is required to interact with and maintain it. Because of this, it is imperative that the workers have appropriate training prior to interacting with the robots Star mentions this concept as technology being visible when broken. That is, the normally invisible quality of infrastructure should be detectable when it is not working as intended. Even if there are backups in place or if the right people are notified, it should still be obvious to workers that the system is malfunctioning

However, many worker injuries have been attributed to being caused by the robots themselves, largely because of this lack of visibility when broken. For example, a software engineer diagnosing two robots in the Austin Tesla factory was attacked by a third malfunctioning robot, resulting in lacerations on his left hand (Zilber, 2023). Although direct injuries like that are way less common, the possibility of robots going rogue is nonetheless worrying. In 2023, Layne performed a Census search and determined that there have been 41 instances of robot-related fatalities in US workplaces over the last 15 years, with 78% of these incidents involving the robots operating on their own power.

Many warehouse employees are also concerned that while there have been recent advances in technology, there has been inadequate training on how to handle, debug, and work with the robots (Lui et al., 2022). Regarding AMRs, a warehouse supervisor said "... if we don't know how to handle [robots], they're hardly going to do any good (Lui et al., 2022)." In the same interview, a separate supervisor at a global automotive manufacturing firm mentioned that if AMRs broke down, most workers would have no way to fix the problem, and thus production could come to a grinding halt or slow down significantly. The potential dangers of untrained workers interacting with rogue AMRs is not worth the risk. As a risk reduction measure, OSHA recommends that workers interacting with robots receive regular training on safely interacting with AMRs, maintaining them, and detecting if they malfunction.

Limitations and Future Research

One limitation of this research is the lack of direct interaction with AMRs in warehouse settings. The study relies on secondary data, including injury reports, worker interviews, and corporate statements, but first-hand observation or direct engagement with AMRs and warehouse employees could provide deeper insights into the day-to-day challenges and hazards that workers face when working alongside these machines. Future research could incorporate direct studies testing specific worker interactions with AMRs instead of relying on generalized statistical or anecdotal evidence. Additionally, much of the analysis focuses on Amazon, which is the largest warehouse robotics company and is a company most people are familiar with. However, this focus may not fully capture the broader impact of AMRs across different industries with varying levels of automation and workplace policies. In the future, this scope could be expanded to other major warehouse operators, both in the US and internationally, providing a more comprehensive perspective on the relationship between workers and AMRs. From an STS perspective, applying other theoretical frameworks, such as Actor-Network Theory, could further reveal the social and financial implications of AMR integration into warehouses.

Conclusion

The integration of AMRs in warehouse environments has significantly increased productivity and profit, but it has also introduced significant challenges related to worker safety, job security, and workplace conditions. While AMRs reduce the need for physically demanding tasks, their presence has coincided with rising injury rates, increased worker stress, worker overexhaustion, and heightened fears of job displacement. These findings highlight the need for companies to prioritize worker mental and physical health alongside profit and efficiency. More broadly, this research emphasizes the importance of regulatory oversight, worker-centered wellness programs, and human-focused usage of AMR technology. As companies continue to adopt AMRs, ongoing research and policy interventions will be essential to balance technological advancement with fair and safe working conditions.

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