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The Future of Warehouse Work: Technological Change in the U.S. Logistics Industry

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Executive Summary

Are "dark" warehouses, humming along without humans, just around the corner? Predictions of dramatic job loss due to technology adoption and automation often highlight warehousing as an industry on the brink of transformation. The potential elimination of many blue-collar jobs is a pressing issue for policy makers and raises important questions about how workers will fare in the economy of the future.

In contrast to reports focusing only on the number of jobs that could be lost, our research offers an in-depth, detailed look at the range of ways in which warehouse work and the industry as a whole might change with the adoption of new technology over the next five to 10 years. The findings in this report are based on in-depth industry research and extensive interviews with a broad set of stakeholders, including industry analysts and consultants, third-party logistics (3PL) operators, retailers, brands, and technology providers. Specifically, we sought to find out:

1. What key industry dynamics are playing a role in technological change?
2. How will adoption of new technologies impact warehouse facilities and operations, as well as the overall organization of the industry?
3. What tasks and processes are the highest priorities for technological application, and how might adoption of new technologies impact jobs in warehousing?

Many accounts of technological change portray firm decision making as purely based on a desire to automate to reduce labor costs. While labor cost reduction plays an important role, our research found a multifaceted set of factors shaping firms' decisions about how to apply new technologies in warehouses. One set of trends—tight labor markets, rising real estate costs, and increasing speed requirements—are pushing warehouse operators to explore new technologies. On the other hand, variability and unpredictability, outsourcing dynamics, inertia, and the state of technological innovation are factors that may slow the process of technology uptake.

As a result, we project that the industry likely won't experience dramatic job loss over the next decade, though many workers may see the content and quality of their jobs shift as technologies are adopted for particular tasks. Employers may use technology in ways that decrease the skill requirements of jobs in order to reduce training times and turnover costs. This could create adverse effects on workers, such as wage stagnation and job insecurity. New technologies potentially can curtail monotonous or physically strenuous activities, but depending on how they are implemented, may present new challenges for worker health and safety, employee morale, and turnover. Additionally, electronically mediated forms of monitoring and micro-management threaten to constrain workers' autonomy and introduce new rigidities into the workplace.

These changes will have a greater impact on communities with high concentrations of warehouse workers. Warehouses typically are clustered near major transportation arteries and population centers—for example, the Inland Empire in California and the Chicago region. Two-thirds of front-line warehouse workers are people of color, most of them Black or Latinx, who stand to be disproportionately affected by technological change. Women are more likely to work in the growing e-commerce sector than in traditional warehouses, so they may benefit from growing employment opportunities, but also face lower wages and increasing pressure from changes in working conditions.

Findings

Technology Meets Shifting Industry Dynamics

1. The warehousing industry is characterized by slim profit margins and cost-sensitive competition, which leads to a cautious approach to technology adoption.

Viewed mainly as a cost center, warehousing is a low-margin industry with high levels of volatility and risk. Cost-based, risk-averse competitive dynamics lead warehouse operators to reduce exposure to cost wherever possible. This is one main reason the industry has lagged in its adoption of new technologies.

Broadly speaking, warehouse operators have thus far moved cautiously into risky experiments with new technologies, relying instead on streamlining current processes and on workforce experimentation. Our research suggests that this trend will continue—the cost sensitivity of the dominant business model will moderate the rate of technological experimentation and uptake, though larger firms may be able to leverage volume and a strong financial position to adopt new technologies. Absent a major shift in how warehousing activities are valued, the dynamics that have created barriers to innovation and contributed to the sector's status as a laggard are likely to persist over the next five to 10 years.

2. E-commerce is driving experimentation with new technologies.

With double-digit sales growth each year, few shifts in consumption patterns have had a greater impact on the warehousing industry than the rise of e-commerce. Online shopping is leading the transformation of the warehousing industry and is poised to have substantial effects on jobs and workers, not least in the realm of adoption of new technologies. E-commerce order picking requires more labor and, given the prompt delivery expectations of consumers, the order fulfillment process is accelerated. This results in a growing need for workers in warehouses, and an increasing interest in technologies that can streamline work processes and improve efficiencies.

Additionally, Amazon's influence in the online retail arena is substantial, particularly in the context of the company's announcements of increasingly faster delivery promises. Whereas a few years ago, consumers were content for an order to arrive in a few days, the delivery window has steadily narrowed with the growing prevalence of Amazon's Prime subscription. The combination of labor-intensive order picking and the speed with which these orders must be shipped has made e-commerce a leading driver of growth in warehousing employment, and is motivating experimentation with new technologies to support the order fulfillment process. This includes technologies that de-skill or potentially displace workers, such as automated picking processes, as well as technologies that speed up, control, or streamline human labor, such as electronic productivity monitoring.

3. Technology uptake likely will be uneven.

Across firms, within firms, and across technologies, adoption likely will vary significantly. Our research confirmed that warehouses are in disparate stages of their techno-strategy development, and that most firms are cautiously exploring new innovations. The business profile of a company, including the specific activities occurring in warehouse facilities, amount of goods being moved, and product markets, all help determine the propensity for technology adoption.

Within firms, a broad set of tasks and activities potentially could be high priority for applications of new technology and automation. Firms must make choices about which activities take precedence, leading to a variegated landscape of technological sophistication across activities in a warehouse. Our research documented that even firms at or near the leading edge of innovation in one area often lag behind in other areas. In one example, a large parcel company had made significant investments in a high-throughput conveyor and automated radio frequency barcode scanning system, but managers still were using spreadsheets and a whiteboard to schedule workers to handle package volumes. Another indication of unevenness is in the market penetration of warehouse management systems (WMS)—a common type of software used in the industry. Using a WMS is a fundamental building block for the adoption of many other technologies, and yet it is estimated that at least one-third of warehouses in the United States do not use such a system.

We project there will continue to be uneven uptake across technologies, in large part because the new technologies tend to be specialized to particular warehouse activities. The modularity of some new technologies, as well as alternative models of leasing, changes the capital investment and risk assessment scenarios in ways that could facilitate firms' technology experimentation and uptake.

4. Technology potentially will have large impacts on third-party logistics firms and outsourcing in the warehousing industry.

Outsourcing is a significant trend in the warehousing sector that affects the pace and forms of technology adoption. New technologies also have the potential to change firms' behavior with respect to outsourcing, which typically takes two forms: (1) outsourcing warehouse management

and operations to third-party logistics firms (3PLs), which offer a wide range of logistics-related services, and (2) outsourcing of warehouse hiring to temporary staffing agencies.

3PLs and temporary staffing agencies are navigating an uncertain landscape of strategies. Some are exploring new roles that leverage technology, while others appear to be taking a wait-and-see approach without significantly altering their value propositions. One 3PL company, for example, coped with a tenfold increase in holiday shopping volume by switching its facility to a highly manual process during peak season and hiring hundreds of extra workers, because the conveyor system could not accommodate the influx of orders. Other warehouse operators reported exploring the use of on-demand staffing platforms, which could simplify hiring processes for the benefit of employers and workers. However, using such tools also may encourage employers to reduce the number of direct hires and increase reliance on temporary workers, who tend to be paid less and have fewer protections on the job.

Also, 3PL contracts often are short (three to five years), which makes a return on investment difficult to achieve for warehouse operators taking on major investments in new technology. Many 3PLs have avoided such investments because of the possibility of losing the customer at the end of a contract, thus eliminating any potential gains. Despite these disincentives, some large 3PLs like DHL and XPO are piloting technologies to better meet the needs of their customers. Similarly, the president of a mid-sized 3PL said his company was exploring how it might commingle smaller e-commerce startups in a single facility and implement automation across all of them in order to speed up order fulfillment.

Impacts on Tasks, Jobs, and Workers

1. New technologies are likely to lead to work intensification.

The highest priority for companies in the short term is to identify and implement technologies that support more efficient order fulfillment. This includes applying labor-saving technologies to high-volume e-commerce order picking and frequent, small-batch replenishments to retail stores that keep limited inventory on hand. The labor-intensive nature of picking individual items to assemble orders—so-called "each picking"—requires large numbers of workers, so warehouse operators place great value on finding ways to reduce headcount and/or increase throughput by reorganizing this activity.

Our research suggests that even though some technologies could alleviate the most arduous tasks of warehouse work (such as heavy lifting), this likely will be coupled with attempts to increase the workload and pace of work, with new methods of monitoring workers. Amazon, for example, introduced MissionRacer, a video game that pits workers against one another to assemble customer orders fastest.

The increasing pace of work in warehouses may introduce new health and safety hazards, as well as increased employee turnover due to overwork and burnout. Currently, warehouse workers

experience work-related injuries at a rate nearly twice that of other private industry workers—higher than construction, coal mining, and most manufacturing industries. According to The New York Times, pregnant workers at a warehouse in Memphis managed by the 3PL XPO were denied requests for light duty and subsequently suffered miscarriages. Warehouse employees also often toil in facilities that are not climate controlled, which exacerbates the hazards created by work speed-up.

2. New technologies have the potential to de-skill some jobs.

Some warehouse technologies are designed to simplify aspects of warehouse work by breaking a job into subtasks and, where possible, removing the skills required of the workforce. Across all occupations in warehouses, viable technologies are likely to replace some human-performed decision-making tasks with machines, significantly changing the composition and quality of jobs. In some cases, the de-skilling appears to be motivated by a desire to shift labor strategy, including expanding the size of the potential labor market, increasing the use of temporary workers, reducing the workforce in certain occupations, and enhancing worker productivity.

Training workers to perform higher-skilled tasks is one potential avenue for adaptation to technological change, but this strategy appears to be underutilized in warehousing. Instead, labor reallocation likely will dominate in the short and medium term, supported by processes of de-skilling and work intensification. For example, the Kiva robotic picking system simplifies the role of humans in picking, reducing training and skill requirements, and making it easier for companies to hire temporary labor rather than direct employees.

3. New technologies are poised to transform how workers are managed.

Algorithmic management introduces new forms of workplace control, where the technological regulation of workers' performance is granular, scalable, and relentless. Newly available devices—such as "wearable" warehouse technologies, autonomous mobile robots, and increasingly sophisticated labor management software—allow close tracking of workers' movements, including walk speed, routes, bottlenecks, and break time.

These technologies have the potential to improve efficiency by urging workers to increase speed and accuracy. These same technologies also can function as a form of surveillance over workers, reducing the little autonomy they already have and further intensifying the pace of their work. Without interventions to ensure the transparency and fairness of the algorithms used in these technologies, the conditions of work in warehouses may be heading toward more rigid forms of monitoring and management.

4. In the short to medium term, new technologies likely will not cause widespread job loss.

With continued growth in demand, aggregate employment levels in the warehousing industry will likely continue to rise over the next five to 10 years. That said, job growth may be tempered by the increased use of labor-saving technologies in e-commerce warehouses in particular, such as autonomous mobile robots, autobaggers and autoboxers, and sensors or RFID tags applied to goods. Honeywell, for example, has developed robotic unloading machines that reduce the offloading time and concomitantly the role of workers in the process.

Many workers may see the nature of their working conditions shift as technologies are adopted for particular tasks over the next five to 10 years. Over the long term, in the absence of major shifts in the economy or context of firms' technological adoption strategies, the increasing use of technology points to a labor reduction.

5. Technology is likely to have uneven impacts across demographics and occupations.

Because of the overrepresentation of workers who are young, male, Latinx and Black in the warehousing industry, these groups of workers will be affected disproportionately by technological change. In particular, Latinx and Black workers are overrepresented in the industry compared with the total U.S. workforce: both groups are employed in warehousing at twice the rate of all other industries. Latinx workers alone compose the largest single race/ethnic group in front-line warehousing jobs, at 35%. Black workers make up one-quarter of the workforce in both warehousing and e-commerce. Overall, workers of color constitute 66% of warehousing industry workers and 55% of workers in e-commerce, even though workers of color account for just 37% of the total U.S. labor force.

Other groups also will experience specific consequences from technological change in warehouses. Some technologies will disproportionately impact the employability of older workers, such as engineered productivity standards that penalize workers for not reaching exacting targets, or newer forms of technology for which older workers do not have training or experience. Women are more likely to be employed in e-commerce warehouses versus traditional warehouses, so the growth in e-commerce offers new employment opportunities for female workers. However, jobs in e-commerce warehouses typically have lower wages and less predictable schedules, and they are even more vulnerable to pressure to increase speed.

Finally, technological change will have different effects at the occupational level. Front-line occupations such as order pickers will likely see the content and quality of their jobs change with the application of new technologies that reduce low-value activities like walking and such automatable tasks as boxing orders. Forklift drivers may work alongside partially automated forklifts, and shipping clerks might see their work increasingly replaced by artificial intelligence.

Conclusion

Our findings raise a number of questions for policy makers, worker organizations, and industry leaders in the warehousing sector:

- How can policy makers, equipped with forward-looking information, help to plan and prepare for changes in job quality and the potential unequal distribution of the costs and benefits of technology adoption?
- How can workers be included in the process of technology implementation to improve employment and operational outcomes?
- What measures can be put in place to track the physical and psychological impacts of technologies on workers, and to mitigate any negative effects on workers' health and safety?
- How can policy makers involve employers in systematically identifying within-industry job opportunities for displaced warehouse workers, including on-the-job training?

In short, how the gains from technological change will be distributed is a pressing question for all of the industry's stakeholders. While large retailers may be able to leverage their sizeable order volumes and strong financial positions to secure first-mover advantages through early adoption of new technologies, many 3PLs and smaller firms will face challenges, primarily the cost-based competition that is prevalent in the warehousing industry. Consequently, widespread automation of the warehousing industry is unlikely in the near to medium term. Experimentation with a variety of new technologies—including but not limited to those that may de-skill and intensify work—appears to be led by the widespread desire to compete with Amazon and other major online retailers.

Technologies are neither inherently good nor bad, just as the effects on employment are not inevitable. Ultimately, warehouse operators have latitude in determining how new technologies will be implemented. For example, when the wholesale retailer Boxed introduced cutting-edge automated processes into its warehouses, it retrained existing workers to fill new roles around these processes instead of laying them off.

The warehousing industry could realize significant operational improvements through technological advances—and it is imperative that productivity gains be shared, that workers be involved in identifying which efficiencies should be prioritized and what hazards are being introduced, and that experimentation unfolds with regard for more than just productivity increases and cost-cutting. Absent this, the process of technological change in warehousing likely will resemble a win-lose proposition, where the short-term benefits are captured by the industry and the long-run costs are borne by workers.

Glossary

The meaning and usage of many common terms vary significantly across the industry. The definitions given here are intended only to help the reader understand how we will use these terms in this report, which may differ from specific legal or regulatory definitions and/or informal usage within particular firms or industry segments.

3PL – Third-party logistics company, which offers outsourced logistics services, including warehousing.

Lead Firm – The most powerful company driving a supply chain, often with forward and backward linkages to other firms through contracting.

Lead Time – The time between when a store replenishment order is placed and the moment it is needed.

SKU – Stock keeping unit, an alphanumeric identifier for a product that helps in inventory management.

Throughput – The amount of goods moving through a warehouse.

WMS – Warehouse management system, or software that allows a warehouse to control and administer operations.

SECTION ONE:
Introduction

There's a certain meditative quality to watching robots stack boxes in a warehouse—and judging from the 3.5 million views one YouTube video by robotics company Boston Dynamics[1] has garnered, many people are drawn to this preview of society's potential future. So-called "dark" warehouses might be full of these robots, toiling alongside stacks of goods and conveyor belts that swiftly carry packages across cavernous buildings and sort goods to their final destinations, all under the supervision of just a handful of human workers. In some ways, this is a desirable vision of the future, because it suggests that the problem of monotonous, manual work in warehouses has been solved by technology, leaving humans to take on the tasks that require higher cognitive functioning. In this scenario, could the technologically enhanced future of warehouse work mean increased efficiency, lower costs, and less grueling work—a win for everyone?

This research sought to examine this question, and the short answer is: without proactive measures, perhaps not. Instead, the potential gains from implementing new technologies in warehouses could be captured by the industry—while the losses fall to workers.

Warehouse operators stand to gain substantial efficiencies through the adoption of new technologies, and e-commerce is the driving force behind experimentation. Despite the growing range of available technologies, however, the warehousing industry faces significant impediments to widespread uptake, and adoption will be uneven across firms in the industry. As a result, in the short to medium term, the industry likely won't experience dramatic job loss, even as many workers may see the content and quality of their jobs shift as technologies are adopted for particular tasks. Technology and automation potentially could reduce monotonous or physically strenuous activities, but depending on how they are implemented may present new challenges for worker health and safety, employee morale, and turnover. As some occupations undergo de-skilling, employers benefit from reduced training times and turnover costs. The effects on workers, however, could entail wage stagnation and job insecurity. And electronically mediated forms of monitoring and micromanagement threaten to constrain workers' autonomy and introduce new rigidities into the workplace.

The labor market impacts likely will be uneven: workers who are young, Latinx and Black, and male are overrepresented in the front-line warehouse workforce and thus may be disproportionately affected by technological adoption. But technologies are neither inherently good nor bad, and the outcomes of employment change are not inevitable. Our research suggests that policy makers, worker organizations, and industry leaders alike must pay careful attention to the distribution of gains and losses from technological change to ensure broadly shared prosperity.

What is the "Future of Work?"

Warehousing is just one sector in which new technologies are forecasted to upend the status quo. More broadly, the uncertainty roiling around the so-called "future of work" has entered the mainstream. Over the last five years, debates about how work is changing largely have been waged by management consultants, in think tanks, among academics, and, to a lesser extent, in policy circles. What became clear, especially as popular media began to cover the shifts in the economy and the organization of industries, was that Americans instinctively feel greater insecurity is more and more a fact of life—whether that comes in the form of fissured work or technology-induced unemployment. The advent of ridesharing platforms and other forms of "gig" work have led to much hand-wringing that more traditional forms of employment are being consigned to a bygone era, though there is little evidence of seismic shifts toward "alternative" work arrangements.[2]

Technological change long has been a subject of human fascination, by turns exciting and alarming us with its potential for societal transformation. The application of new technologies to reorganize human labor has been a central theme of the future of work conversation, and media attention has brought the topic to readers and viewers in all corners of the country. What began as quasi-apocalyptic predictions about impending mass job losses[3] has shifted, in a welcome development, to somewhat more nuanced discussions of the content of work, and which tasks and workers might be most affected by technological change.[4] Still, most aggregate studies of the impacts of technology on jobs hover in their analysis at 30,000 feet, which obscures the conditional, lurching processes through which technological change usually occurs. The view from this elevation unintentionally has promoted a narrative of inevitability, with technological change foreshadowing a putative "end of work."

The Future of the Warehouse

Instead of adhering to the notion of a fated future, this research takes seriously the ways in which technological change is *produced* by a range of actors and processes. Warehousing often is cited as one industry that will be revolutionized by automation, perhaps in part because it for so long has been a laggard in technological adoption—especially when compared with its sister sector, manufacturing.

The warehousing industry is responsible for the storage, flow, and rerouting of goods to consumers or stores. The looming possibility of dark warehouses and other forms of automation that replace workers in warehouses dominates popular media reports about the industry. Yet there are many forms of technology that have the potential to change tasks and jobs in the warehousing sector without drastically reducing the need for workers in the short to medium term. This report explores a range of possible changes in the content and quality of work that might be borne of new technological applications in the warehouse.

Warehousing is an essential, if often invisible, element of the economy: it is the circulatory system through which goods move. Employment in the sector has been rising steadily since 2001, and growth has been particularly brisk over the last few years. From 2014 to 2017, employment rose by 37%, a phenomenon that largely can be attributed to e-commerce, for which sales grew by 52% over the same period. Wages, however, have not seen such growth. Rather, according to the U.S. Bureau of Labor Statistics, inflation-adjusted average wages actually haveww fallen since 2001.

“Research suggests that policy makers, worker organizations, and industry leaders alike must pay careful attention to the distribution of gains and losses from technological change to ensure broadly shared prosperity.

The industry also is undergoing significant change. The rise of e-commerce has increased demand for fast, efficient warehouse operations, even as it also introduces new levels of complexity in assembling and shipping orders. Retailers with a brick-and-mortar footprint have struggled to develop new direct-to-consumer fulfillment strategies as they endeavor to satisfy changing consumer expectations regarding product selection, cost, and delivery timetables—fueled by Amazon’s sophisticated logistics infrastructure. An array of order fulfillment strategies has emerged. For example, some firms have added a “buy online, pick up in store” option, or BOPIS, filling online orders from brick-and-mortar store inventory and offering quick-turnaround pickup at the store itself. This new order delivery channel blurs the boundaries of the warehousing industry and highlights the considerable change under way in the sector.

Growing online sales have increased demand for warehouse workers and, at the same time, have produced a surge of interest among warehouse operators in how new technologies could help make the e-commerce order fulfillment process more efficient and less labor-intensive. While the industry historically has been slow to adopt new technologies, it appears to be reaching a decision point: tight labor markets, the emergence of e-commerce, and the capabilities of new technologies are converging to push firms to more seriously explore automation. Absent major shifts in the economy, the future likely portends considerably more widespread technological adoption, but in most cases it probably will proceed in a piecemeal fashion, applied to particular warehouse activities.

Research Questions

In an effort to understand the choices of and constraints facing warehousing industry actors, this study set out to assess short- and medium-term (over the next five to 10 years) technological change in the distribution function of global supply chains, and its potential impacts on the organization of employment and work tasks. Data collection focused on three main questions:

1. What key industry dynamics are playing a role in technological change?
2. How will adoption of new technologies impact warehouse facilities and operations, as well as the overall organization of the industry?
3. What tasks and processes are the highest priorities for technological application, and how might adoption of new technologies impact jobs in warehousing?

Data and Methods

This report relies on primary data collected through interviews with industry leaders and analysts, as well as attendance at logistics conferences and industry trade shows. Twenty-nine interviews were conducted between November 2018 and March 2019 in person and by telephone. Interviewees with a variety of perspectives were consulted, including management consultants, third-party logistics (3PL) operators, retailers, brands, and technology providers. Industry trade publications such as Supply Chain Quarterly, WERCWeekly, and SupplyChain 24/7 provided a wealth of information on the state of technological advance in warehousing. Finally, supplementary analysis drew on data from such government sources as the Bureau of Labor Statistics (BLS) and the U.S. Census Bureau.

To be clear, what was outside the scope of this analysis was quantitative modeling of potential future job losses in the sector. Other studies have offered projections of the impacts of technological change on employment levels, and these are discussed herein. Rather, the intent of this research was to get close to the ground, gathering perspectives from across the industry in order to examine the political economy of technological change.

Section 2 presents information on the warehousing industry. Section 3 offers a framework for understanding technological change and its impacts on workers. Section 4 lays out leading technologies and discusses the contextual factors that shape decision making about new technologies. Section 5 provides findings on the current trends and future impacts of technological change on the warehousing industry as a whole, and Section 6 builds on this with an analysis of how work is likely to change. Section 7 concludes with suggestions for policy and practice.

SECTION TWO:
The Warehousing Industry

Some background on the warehousing industry and its workforce will help lay the groundwork for understanding the opportunities and challenges the industry faces, as well as the pathways technological change might take in the coming years. This section presents an overview of the structure of the industry, followed by workforce demographics, the distribution of occupations, and worker pay.

Structure of the Industry

Warehousing involves the storage, flow, and rerouting of goods through physical buildings. The industry employs just more than 1 million workers who collectively earn wages approaching $50 billion annually.[5] According to County Business Patterns (2016), there are just more than 15,000 warehousing establishments in the United States, the majority of which are small, employing fewer than 20 workers. However, while establishments with 100 or more workers account for just 12% of total establishments, they account for the lion's share of employment—73% of all warehouse workers work in these facilities.

The central function of warehouses is the efficient calibration of goods production and consumption—a critical component of the U.S. economy. Figure 2.1. shows warehousing in the context of a simplified modern supply chain.

Figure 2.1
Simplified Supply Chain

There are a few key features of the warehousing industry that are useful to point out.

Changing Warehouse Operations

Shifts in consumption patterns and the organization of supply chains have led to significant change in the warehousing industry, forcing distribution centers from a storage function to one where, ideally, goods are in near-constant movement. A "traditional" warehouse is shorthand for distribution centers that deal mainly in pallets and cases (full boxes of goods). For these facilities, goods arrive at the warehouse on a pallet or in boxes packed directly on the floor of a shipping container. During the time these goods are in the warehouse, they will remain either palletized or in cases. These arrangements improve the efficiency of moving and storing bulk goods: for example, 4,000 calculators can be moved in a single forklift trip. Traditional warehouses are more likely to be receiving and shipping full pallets or cases of goods to a retail store or other business.

The basic categories of warehouse activities include:

- **Receiving:** Unloading goods and preparing them either for storage or transshipment. This can also include returns.
- **Put-away:** Moving goods to their next location within a warehouse.
- **Storage:** Holding goods until they are needed.
- **Picking:** Selecting and assembling orders per item, case, or pallet. This also may include final assembly, labeling, or packaging.
- **Shipping:** Preparing orders for shipment and loading goods.

While these activities still remain central to warehouse operations, the profile of the industry has shifted over the last decade as online shopping has gained retail market share.

E-commerce Warehouses

With double-digit year-over-year sales growth, few shifts in consumption patterns have had a greater impact on the warehousing industry than the rise of e-commerce. According to the U.S. Census Bureau, just more than 10% of retail sales in the second quarter of 2019 were conducted online.[6] E-commerce distribution centers comprise 20% of new industrial leasing activity,[7] which reflects the current phase of expansion and the need for more space to fulfill online orders. The e-commerce segment is expected to grow in the coming years, and will continue to drive demand for efficient warehousing operations.

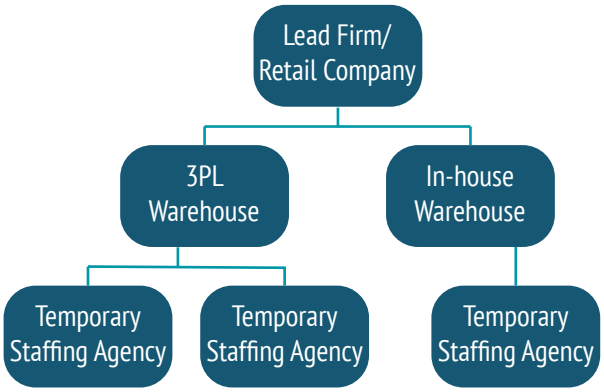
The rise of e-commerce has introduced a new set of activities into warehouse operations, both because of the nature of online orders and the speed with which they must be processed.

E-commerce customer orders consist of "eaches," or quantities of one, for multiple products stored within a warehouse. Items for a single order likely will be located in different areas of the facility, and they must be consolidated in one place to be packed and shipped together, a process called each-picking order assembly. Furthermore, customers expect the shipment to arrive quickly—Amazon has set high expectations among consumers for fast, cheap delivery. For these reasons, the e-commerce picking process is far more labor intensive and time sensitive than traditional warehouse activities involving the bulk transfer of products.

Outsourcing

Two forms of outsourcing are prevalent in warehousing: 1) contracting for warehouse operations, and 2) contracting for labor. Companies often pursue a mix of in-house and outsourced warehouse operations (Figure 2.2.). Over the last 15 years, third-party logistics companies, or 3PLs, have proliferated as lead firms that do not consider warehousing to be a core competency have sought outsourcing options; in 2017, revenues in the contract warehouse sector topped $40 billion.[8] The lack of systematic, representative data makes it difficult to track long-term changes in warehouse outsourcing;[9] however, according to one study, 66% of shippers now outsource their warehousing needs.[10]

FIGURE 2.2
Stylized Map of Warehouse Outsourcing



3PLs provide a number of services and value-added activities for part or all of their customers' distribution needs—for example, Walmart contracts with 3PLs to manage the distribution of oversized goods like tires, while keeping fulfillment of other retail goods in house.[11] In another case, a grocery store chain like Meijer might contract with a 3PL to provide final brand labeling on canned goods. On balance, though, the most common activities to be outsourced are transactional, repetitive operations, such as unloading containers of goods.

The leading 3PLs aren't necessarily household names: while DHL is well known, other major players like XPO Logistics, Kuehne + Nagel, GEODIS, and CEVA Logistics are not. Yet they play an important role in providing logistics services to their clients, which include retailers, grocery chains, consumer electronics companies, and brands.

Competition in the 3PL market is cutthroat, and a key determinant for whether one 3PL wins a contract over another is price. In a 2017 survey, 77% of lead firms reported that "lowest cost" was the single most important factor in selecting a 3PL provider.[12] And while 3PLs often offer a comprehensive suite of services for clients, there is little evidence that lead firms are, on the whole, seeking higher value-added services. Instead, transactional activities compose the bulk of 3PLs' contracts. As a result, 3PLs operate in highly competitive, price-sensitive markets where the primary value proposition is one of reducing costs (as opposed to differentiating service offerings). Furthermore, lead firms' contracts with 3PLs tend to last for just three to five years before being rebid, making strategic partnerships between companies more difficult. These factors, in turn, have ripple effects on how work is organized and, ultimately, on the feasibility of introducing new technologies into warehouses.

One key capacity offered by 3PLs is management of warehouse labor, including the outsourcing of workforce needs to temporary staffing agencies that provide just-in-time staffing for warehouse facilities. Temporary staffing agencies have assumed a central role in helping warehouses manage market volatility, and several logistics-related occupations are among those with the highest temp penetration rates.[13] For example, according to the BLS, laborers and hand material movers are the largest warehouse occupation, making up 44% of front-line workers; laborers are also the largest occupational category in temporary help services, with more than one half-million workers. The two largest employing industries for the laborers occupation are temporary staffing, which employs 18% of all laborers, and warehousing, where 10% work.[14]

In warehousing, there are powerful inducements to hold down the cost of labor, and the negative short- and long-term effects on workers, in particular sizable wage differentials between temporary and direct-hire employees, are well documented.[15] These wage differentials raise important questions concerning the labor strategies of warehouse operators and the workforce systems they adopt, even as technological change appears poised to unsettle existing staffing arrangements.

Geographic Concentration of Warehouses

Warehouses often are clustered near major transportation arteries and population centers. Over the last decade, warehouse developers and operators have sought inexpensive land for new, large-scale distribution center projects, which often meant siting buildings in suburban or exurban areas. For example, the Riverside-San Bernardino-Ontario, California, Metropolitan Area, also known as the Inland Empire, is roughly 60 miles east of Los Angeles and home to the highest concentration of warehousing employment in the country (Table 2.1.). Because of the clustering of

warehouses in particular geographic areas, any shifts in employment caused by new technologies will have greater impacts in these areas. Online shopping and customer expectations for fast delivery, however, have increased demand for smaller, last-mile e-commerce distribution centers near densely populated areas.[16] This trend is shifting the geography of warehouses toward urban cores.

TABLE 2.1
Top Ten MSAs for Warehousing Industry Employment, 2018

Metropolitan Statistical Area	Warehousing Industry Annual Average Employment (2018)
Riverside-San Bernardino-Ontario, CA	68,673
Chicago-Naperville-Elgin, IL-IN-WI	51,006
New York-Newark-Jersey City, NY-NJ-PA	49,945
Dallas-Fort Worth-Arlington, TX	44,273
Atlanta-Sandy Springs-Roswell, GA	31,165
Los Angeles-Long Beach-Anaheim, CA	27,271
Columbus, OH	26,213
Indianapolis-Carmel-Anderson, IN	26,121
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	23,942
Phoenix-Mesa-Scottsdale, AZ	20,103

Source: Quarterly Census of Employment and Wages

The Warehouse Workforce

As we discuss later in this report, there are significant technological changes on the horizon in the warehousing industry. As a result, many workers may find their occupations reshaped and the quality of their jobs undermined. The makeup of the existing warehouse workforce is analyzed below.

The fortunes of the warehousing industry are closely tied to consumer spending and the strength of the national economy. The industry has been in a period of sustained growth. According to BLS data, with the exception of a dip during the 2007–09 Great Recession, employment growth has been strong since 2001, with a marked increase recently—the industry experienced 37% employment growth between 2014 and 2017 (Figure 2.3.).[17] Much of this increase can be attributed to the rise of e-commerce sales, which grew by 52% over the same period;[18] BLS predicts employment will continue to grow by 21% between 2016 and 2026.[19]

Typically, when an industry experiences this level of employment growth, rising labor demand leads to rising wages. In the warehousing industry, however, inflation-adjusted wages actually have fallen since 2001 (Figure 2.3.). This may provide *prima facie* evidence that, in key locales, warehouse facility operators are exerting monopsony power within their local labor markets. The concentration of warehouse facilities in distinct geographical areas, such as Southern California's Inland Empire, Will County in exurban Chicago, and the Lehigh Valley in Pennsylvania, appears to be providing employers the latitude to set wages at lower levels than would be reached if job market competition prevailed. This appears to have contributed to wage stagnation in the industry. The spatial concentration of employment in these regions means that warehouse operators dominate many local labor markets, with few employment opportunities outside the even-lower-paying service sector. In such cases, the warehousing industry has considerable latitude in setting wage rates, especially given that unionization rates in the industry also have fallen—from 14% in 1990 to just 6% in 2018.[20]

FIGURE 2.3

Trends in Overall Warehousing Industry Employment and Real Annual Earnings, 2001-2017

Source: Quarterly Census of Employment and Wages

Warehouse Occupations

Table 2.2. presents data on the five largest occupations in warehousing, also referred to in this report as front-line workers, which represents direct-hire workers in facilities classified under the Warehousing and Storage industry code (NAICS 493). The following occupations are the largest in the industry:

- Laborers and Freight, Stock, and Material Movers, Hand
- Industrial Truck and Tractor Operators (Forklift Drivers)
- Stock Clerks and Order Fillers
- Packers and Packagers, Hand
- Shipping, Receiving, and Traffic Clerks

Median hourly wages for these workers range from $13.71 to $16.96; the median hourly wage for laborers, who account for roughly a third of all workers in warehouses, is $15.85. Yet because of the way data on the industry are compiled, this table presents an incomplete picture of employment and wages. In addition to direct-hire employees, warehouse operators also rely, to varying degrees across facilities and times of the year, on workers supplied by temporary staffing agencies; these workers are not included in Table 2.2. Also absent are workers in common warehouse occupations employed in e-commerce warehouses (NAICS 45411, Electronic Shopping and Mail-Order Houses; this industry category captures some, but not all e-commerce facilities, with the remainder included in NAICS 493).

TABLE 2.2

Employment and Hourly Median Wages for the Five Largest Occupations in the Warehousing Industry, 2018

Occupation	Employment	Hourly Median Wage
Laborers and Freight, Stock, and Material Movers, Hand	329,540	$14.58
Industrial Truck and Tractor Operators (Forklift Drivers)	183,350	$16.96
Stock Clerks and Order Fillers	99,770	$15.35
Packers and Packagers, Hand	68,340	$13.71
Shipping, Receiving, and Traffic Clerks	59,880	$15.85

Source: Occupational Employment Statistics

Difficulties accurately counting warehouse workers have led to vast variations in employment estimates: on the low end, BLS estimates 1 million workers,[21] while a recent McKinsey report estimates 4 million.[22] The blurred boundaries of the industry also appear to inflate the wages typically reported for the industry. Some workers in e-commerce, and those employed through temporary staffing agencies, earn less per hour than direct hires in the warehousing industry. For example, according to BLS, shipping and receiving clerks, stock clerks, and packers in e-commerce warehouses earn between 6% and 15% less per hour than the same occupations in traditional warehouses.[23] In short, 1 million warehouse workers is likely a conservative estimate of total employment, and $13.71 to $16.96 is probably higher than the overall median wage of all warehouse workers.

"Typically, when an industry experiences this level of employment growth, rising labor demand leads to rising wages. In the warehousing industry, however, inflation-adjusted wages actually have fallen since 2001.

Warehouse Worker Characteristics

Analysis of data from the American Community Survey (2013–2017) on the five largest warehousing occupations shows the U.S. warehouse workforce is more likely to be young, Latinx and Black, and male than the rest of the working population. Because there are significant differences in the workforces employed, the data on worker characteristics are presented separately for the warehousing industry (NAICS 493) and the warehousing segment of e-commerce (NAICS 45411), hereafter referred to as warehousing and e-commerce.

Male workers are overrepresented in the industry: while 47% of the U.S. workforce is male, 72% of workers in warehousing and 56% in e-commerce are male (Table 2.3.). And although male workers compose the majority of the workforce in both segments of the industry, female workers are much more likely to be employed in e-commerce than in warehousing—44% of workers in the e-commerce segment are women, compared with just 28% of workers in traditional warehousing.

Latinx and Black workers are overrepresented in warehousing jobs: both groups are employed in warehousing at a rate roughly double that of all other industries. Despite accounting for only 17% of the overall U.S. labor force, Latinx workers compose the largest single racial/ethnic group of front-line workers in warehousing (35%). Similarly, Black workers account for roughly one-quarter of workers in both warehousing and e-commerce, but account for just 12% of the overall labor force. Conversely, Whites are underrepresented in the industry. The proportion of White workers in warehousing and e-commerce is 34% and 45%, respectively, despite accounting for 63% of the overall labor force. Overall, workers of color make up 66% of warehousing industry workers and

55% of workers in e-commerce, whereas workers of color are just 37% of the total U.S. labor force. Warehouse workers tend to be young: workers younger than age 35 make up 56% of warehouse workers and 64% of e-commerce workers.

TABLE 2.3

Demographic Characteristics of Workers in the Five Largest Warehouse Occupations in Warehousing and Electronic Shopping Industries, U.S. Total*

	Percentage of Workers in Warehousing Industry**	Percentage of Workers in Electronic Shopping Industry***	Percentage of Workers in U.S. Workforce, All Sectors
Gender			
Male	72%	56%	47%
Female	28%	44%	53%
Race/Ethnicity			
Black, Non-Latinx	25%	26%	12%
Hispanic or Latinx	35%	19%	17%
Asian, Non-Latinx	3%	6%	6%
White, Non-Latinx	34%	45%	63%
Other, Non-Latinx	2%	4%	3%
Age			
18–24	27%	38%	16%
25–34	29%	26%	24%
35–44	19%	16%	22%
45–54	16%	13%	23%
55–64	9%	7%	15%

Source: American Community Survey 2013–2017

*The largest warehouse occupations are Laborers and Freight, Stock, and Material Movers, Hand; Industrial Truck and Tractor Operators (Forklift Drivers); Packers and Packagers, Hand; Stock Clerks and Order Fillers; and Shipping, Receiving, and Traffic Clerks

** North American Industrial Classification System (NAICS) 493

*** NAICS 45411

Note: Columns may not add to 100% due to rounding.

While female workers are more likely to work in e-commerce than warehousing, the proportion varies significantly by occupation. Table 2.4. shows the gender composition of the five largest occupations in warehousing and e-commerce. In nearly every occupation, women make up a higher percentage of e-commerce workers than warehousing industry workers.

TABLE 2.4

Common Warehouse Occupations in the Warehousing and Electronic Shopping Industries by Gender

	Percent of Workers in Warehousing Industry	Percent of Workers in E-commerce Industry
Laborers and Freight, Stock, and Material Movers, Hand		
Male	78%	70%
Female	22%	30%
Industrial Truck and Tractor Drivers (Forklift Drivers)		
Male	93%	82%
Female	7%	18%
Stock Clerks and Order Fillers		
Male	62%	52%
Female	38%	48%
Packers and Packagers, Hand		
Male	43%	44%
Female	57%	56%
Shipping, Receiving, and Traffic Clerks		
Male	69%	57%
Female	31%	43%

Source: American Community Survey 2013–2017

Warehouse Working Conditions

Front-line workers perform a variety of activities that allow for the movement of goods through warehouses. The main tasks of the five major occupations are as follows:[24]

Laborers and Freight, Stock, and Material Movers, Hand

- Move freight, stock, or other materials to and from storage or production areas, loading docks, delivery vehicles, ships, or containers, by hand or using trucks, tractors, or other equipment.
- Sort cargo before loading and unloading.
- Attach identifying tags to containers or mark them with identifying information.
- Read work orders or receive oral instructions to determine work assignments or material or equipment needs.
- Stack cargo in locations, such as transit sheds or in holds of ships, as directed, using pallets or cargo boards.

Industrial Truck and Tractor Operators (Forklift Drivers)

- Move levers or controls that operate lifting devices, such as forklifts, lift beams with swivel-hooks, hoists, or elevating platforms, to load, unload, transport, or stack material.
- Inspect product load for accuracy and safely move it around the warehouse or facility to ensure timely and complete delivery.
- Manually or mechanically load or unload materials from pallets, skids, platforms, cars, lifting devices, or other transport vehicles.
- Position lifting devices under, over, or around loaded pallets, skids, or boxes and secure material or products for transport to designated areas.
- Weigh materials or products and record weight or other production data on tags or labels.

Stock Clerks

- Pack and unpack items to be stocked on shelves in stockrooms, warehouses, or storage yards.
- Store items in an orderly and accessible manner in warehouses, tool rooms, supply rooms, or other areas.
- Examine and inspect stock items for wear or defects, reporting any damage to supervisors.
- Receive and count stock items, and record data manually or using computer.
- Mark stock items using identification tags, stamps, electric marking tools, or other labeling equipment.

Packers and Packagers, Hand

- Load materials and products into package processing equipment.
- Clean containers, materials, supplies, or work areas, using cleaning solutions and hand tools.
- Record product, packaging, and order information on specified forms and records.
- Examine and inspect containers, materials, and products to ensure that packing specifications are met.
- Measure, weigh, and count products and materials.

Shipping, Receiving, and Traffic Clerks

- Examine shipment contents and compare with records, such as manifests, invoices, or orders, to verify accuracy.
- Record shipment data, such as weight, charges, space availability, damages, or discrepancies, for reporting, accounting, or recordkeeping purposes.

- Prepare documents, such as work orders, bills of lading, or shipping orders, to route materials.
- Confer or correspond with establishment representatives to rectify problems, such as damages, shortages, or nonconformance to specifications.
- Pack, seal, label, or affix postage to prepare materials for shipping, using hand tools, power tools, or postage meter.

The manual nature of much warehouse work is evident in the occupational descriptions above. Repetitive movements, awkward lifting and moving positions, and a fast-paced work environment, together put workers at risk of injury. Indeed, according to BLS, in 2017, warehouse workers experienced work-related injuries at a rate nearly twice that of all private industry workers—higher than construction, coal mining, and most manufacturing industries.[25] In one recent industry survey, 61% of respondents had a warehouse employee turnover rate greater than 10%, with major impacts on productivity and the cost of replacing workers.[26]

Health and safety is one contributing factor to the high turnover rate in warehouses, and recent media reports have highlighted the array of health and safety risks in the industry. Amazon, in particular, has come under fire for the health and safety ramifications of high productivity requirements and the stress workers report feeling as they toil under exacting pressures to perform.[27] In addition, many warehouses are not climate controlled, leading to cold temperatures in winter months and sweltering conditions during the summer; at an Amazon warehouse in Pennsylvania, for example, workers so frequently experienced heat-related episodes, including fainting, that paramedics and ambulances were stationed outside.[28] According to one New York Times account, pregnant workers at a warehouse in Memphis managed by the 3PL XPO were denied requests for light duty and subsequently suffered miscarriages.[29] Such reports point to the challenges that warehouse workers face, which are often exacerbated by the frenetic pace of just-in-time distribution systems and high productivity standards that pervade the industry.

Worker Productivity and Management

Tracking worker productivity long has been a key feature of the warehouse. "Scientific labor management," first introduced by Frederick Taylor in the 1900s, promised to apply principles of science to improvements in labor productivity. Management systems divide work into discrete subtasks, each of which is subject to time and motion studies of the workers performing the job. The results of these studies form the basis for "engineered labor standards," which in warehouses often are codified in Key Performance Indicators (KPIs) such as volume moved per worker per hour and accuracy (KPIs also include other such nonlabor indicators as inventory accuracy and asset utilization). In unionized warehouses, the development of engineered labor standards are negotiated and agreed upon by both workers and management. No such agreements exist in nonunion facilities.

Industrial engineers conduct audits that assess and reassess warehouse processes for possible gains in efficiency. As the vice president of a large 3PL explained in an interview, "We have a whole engineering team that does nothing but continuous improvement. 'Let's look at the process, figure out how we change it and make it ever so slightly better. Get five seconds out of it.' We don't even want to think about technology [until we've done that]."

Taken together, data on the warehouse workforce offer an aggregate account of the workers who will be most affected by new technologies: these are front-line workers involved in all aspects of the movement and handling of goods in warehouses, exposed to health and safety risks that are exacerbated by high productivity standards. One important factor that shapes workers' experiences of job quality, as well as the broad approach to technological change, is the cost-sensitivity of the warehousing industry.

Economics of the Industry

For all the emphasis on sophisticated, strategic approaches to goods movement that abound in business literature, warehousing largely still is seen as a cost to be contained—a "necessary evil." Warehousing rarely adds an increment of value to the end product—and fast, free shipping and returns reinforce this point—so the dominant dynamic across the warehousing industry is one of low margins and cost cutting.

Two key features of modern supply chains shape the role warehouses and distribution centers play in the wider economy: volatility and risk management. Supply-chain volatility—such as that caused by fluctuations in consumer markets, shifting seasonal cycles, or natural disasters—makes flexibility to adapt to demand and supply instability paramount. Distribution centers are expected to buffer and help manage this volatility through a range of flexible, just-in-time systems.

At the same time, firms' supply chain risk management strategies must contend with a varied set of economic, product market, and regulatory risks, including those arising from trade policies, fluctuations in currency valuations, and changes in consumer spending. All warehouses face volatility and risk, and some lead firms pursue outsourcing in an attempt to shift risk away from their own sphere of responsibility, including onto 3PLs and temporary staffing agencies.[30]

In the context of low margins—according to one industry estimate, warehouse margins average just 3% to 6%[31]—firms' options to manage volatility and risk are constrained. In the past, warehouse operators have relied on experimentation in labor strategies to contend with the challenges of volatility and risk inherent in supply chains—for example, using temporary workers to flex staffing levels up and down with fluctuations in consumer demand. While this trend persists, our research found that there also is increasing interest in using new technologies to address the fundamental business dynamics that shape the industry.

SECTION THREE:
A Framework for Technological Change

With society searching for clues about how work will change, predicting long-term technological unemployment has become fashionable. Think tanks and management consultancies produce aggregate accounts of technological change, often with contrasting conclusions ranging from apocalyptic to modest (mainly due to differing methodologies and assumptions). Unfortunately, most studies have focused narrowly on potential job losses, as opposed to the consideration of a broad spectrum of possible effects of technological change. This research seeks to counteract this tendency by exploring some of the varied ways in which technology potentially could affect employment arrangements, including altering the content and quality of jobs through de-skilling, work intensification, and algorithmic management.

The warehousing industry often is included among the sectors that will be transformed radically by technology, with studies forecasting that a substantial percentage of jobs and activities are automatable. Some examples include the following:

- According to the Brookings Institution, 92% of forklift drivers' tasks and 80% of packers and packagers' tasks are susceptible to automation, while only 7% of the tasks of a laborer are similarly susceptible.[32]
- McKinsey Global Institute estimates that 57% of activities in transportation and warehousing are technically automatable.[33]
- Bain & Company predicts that 70% of job roles in warehouses potentially could be lost through automation.[34]

The Task Model

One common way to understand the relationship between technology and the content of jobs is the "task model" developed by Autor, Levy, and Murnane.[35] The task model suggests that for repetitive and easily programmed operations, new technology tends to replace human

labor, particularly as the cost of technology adoption declines. This, the authors point out, historically has been a key driver of technological change in the workplace. For other operations, the procedures necessary to complete a given task are not understood well enough to be programmed, and thus undertaken by a machine; these are nonroutine operations for which technology can complement human labor and result in increased worker productivity—but not fully replace human labor. Some tasks remain more productively completed by humans, at least until the ability to program the task content is achieved and the price point drops below the cost of labor.

One should not assume, however, that decisions regarding technology adoption are made solely on the basis of hoped-for efficiency or productivity gains, though this is typically how such decisions are framed by those developing new technologies and, often retrospectively, by those who have implemented technological change within their organization. Further, the price point of the technology, while important, is not the only factor influencing technology adoption. Firms' decisions about pursuing new technologies are made in the context of particular forms of governance—that is, these decisions are made in relation to how a given company is organized, the regulatory environment within which it operates, the labor and industrial relations framework through which employment is organized, its relationships to suppliers and end users, and the markets within which it competes. Attention, therefore, should be focused on the interaction of organizational structures and technologies, lest observers misrepresent how particular outcomes, like reductions in workforce size or changes in job quality, are produced. Variation among these interactions within firms' systems of governance helps explain divergences in techno-strategies at the firm level.

The task model would suggest that routine tasks are the highest priority for technology applications. However, this research points to a range of other factors that also shape this decision. The prevalence of manual, routine tasks in a warehouse increases the probability that these activities will, at some point, be candidates for automation, though when and how this occurs is difficult to predict. Herein lies the key weakness of aggregate accounts that predict sweeping job losses in industries and occupations. The specific content of a task shapes alternative methods of organizing the work—for example, the dexterity required to select a particular item for a shipping order constrains the application of (current) technologies to the task of order picking. The technical "automatability" of a task certainly impacts the trajectory of change—it represents the initial step of making it possible to apply a new technology to an activity. Moving from this stage to one of rising probability of technology adoption, and then on to a point where technology adoption pervades an industry, demands attention to industry dynamics and other contextual factors, which are difficult—if not impossible—to model quantitatively. The process of technological change is path dependent—that is, it occurs within a set of social and historical circumstances that carry "embedded interests and ideologies about what problems can or should be 'solved' by technology."[36] The perils of quantitative modeling and the distinct lack of qualitative descriptions that endeavor to account for the range of factors shaping technological change were the impetus for this research.

SECTION FOUR: Warehouses and Technology

Leading Technologies in Warehousing

Warehousing has been a relative laggard industry in terms of adopting new technologies. Over the last 20 years, technological innovation was focused on eliminating data entry and reducing the amount of walking involved in a warehouse worker's activities. The key forms of technology included warehouse management software, radio frequency scanners, and industrial conveyor systems, though the uptake of these forms of automation across firms has been uneven.[37] The following are some of the leading and emerging technologies in warehousing today.

Software

Warehouse Management Systems

Warehouse management systems (WMS), the most common technology deployed across the industry, control day-to-day warehouse operations, including receiving and storage, staging orders, and administering product replenishment. WMS software usually stands as separate modules from, but integrated with, enterprise resource planning (ERP) systems, which send orders to the WMS. In the 1980s and 1990s, many firms developed their own WMS in house and, particularly for 3PLs, unique attributes of their WMS helped create a market niche.[38] Today, these legacy systems are being replaced by highly sophisticated off-the-shelf software packages, such as Manhattan, JDA, and HighJump. WMS software sometimes includes a labor management system module, which increases the ability of managers to plan labor allocation and track workers, and typically integrates engineered labor standards into metrics. Integration of WMS with various hardware systems is a key puzzle for technology developers, and can require a separate system to "translate" between the hardware and WMS, sometimes referred to as a warehouse execution system.

Hardware

Conveyors and Sortation Systems

Large-scale industrial mechanization arrived in warehousing in the 1990s. Conveyors and sortation systems were designed to carry boxes across large expanses and direct the goods to the proper shipping location, thereby reducing workers' time spent walking and sorting. Major capital investments were required to implement these systems, which are heavy, bolted to the floor, and inflexible. Decision making about the adoption of conveyor systems was based on 10-plus-year forecasts of demand volumes, so when first installed, they tended to have excess capacity; because they are costly, mechanized systems often take many years to realize an adequate return on investment. Newer forms of conveyor and sortation systems can incorporate automated scanning and goods sortation for shipment.

Radio Frequency Scanners

Handheld radio frequency (RF) barcode scanners are used to manage inventory and track the order-picking process, replacing the need for paper "pick lists." RF scanners also allow employers to monitor worker productivity. Hands-free RF scanners that attach to a worker's arm and are equipped with a barcode scanner on a finger are replacing handheld scan guns that can cause tendonitis and other ergonomic injuries.

Voice-Directed Systems

Workers using voice-directed systems wear a headset that provides instructions on what items to pick or put away and where they are located, and workers confirm the location and items by speaking standardized commands. Voice-directed systems can replace the need for a worker to read instructions from a list or scan items with a barcode scanner. According to a recent survey, voice-directed systems are one of the fastest-growing technologies in warehouses—roughly one-quarter of facilities reported using voice-directed picking in 2018, up from just less than 6% a decade prior.[39]

Put Walls

Put walls are shelving systems with slots, each representing an e-commerce or store order. They are equipped with lights that direct a worker to put items in particular places. Orders are picked upstream and transported manually or via conveyor or mobile robots to the put wall for sorting into individual orders. Put walls are not highly automated and still require significant amounts of human labor to implement, but are relatively inexpensive and effective in streamlining the picking and order-assembly process.

Goods-to-Person Systems

Goods-to-person systems bring items to the worker for order picking. This can, for example, take the form of a shelf mounted on a robot that makes its way to the picking station, as in the case of Kiva robots in Amazon warehouses, or a hanging bag sorter that brings individual items to a worker via an overhead-mounted pouch. There is a range of automated storage and retrieval systems (ASRS), which combine storage with goods-to-person item delivery. Goods are stored in racking systems, and an automated shuttle retrieves goods and delivers them to the order picker. These systems allow for high-density storage, since they eliminate the need for wide aisles between racks for humans or forklifts, and are the most efficient automated systems currently available. However, they are costly, resembling older forms of mechanization in terms of the capital intensity of implementation and their inflexibility—they are set in place and only can accommodate goods of a fixed maximum size and weight. There are ASRS systems designed for each picking, case picking, and pallet in/out processes, though a single system would not be able to accommodate all three activities.

Autonomous Mobile Robots

Autonomous mobile robots (AMRs) are automated carts that travel around a warehouse, moving items for orders between picking and sorting or packing locations. Two subcategories exist: "relay" carts and "follow-me" carts. Relay AMRs can work with most picking processes; the order picker selects the items for the order, places them in the cart or tote, and the AMR delivers the tote to the next task station. A follow-me AMR leads a worker through the warehouse, setting the pace and directing the worker to select particular items. When the order picking is completed, the follow-me AMR transports the items to the next task station. AMRs are very effective in e-commerce fulfillment environments and in applications with sufficient order volumes. Some users report that the robots can double productivity levels, but higher productivity models cost more to implement, and without adequate volumes, AMRs will not achieve the expected results.

Robotic Picking

In most warehouses, the product-picking process still relies on human hands to select items. The optimal technological case for picking is robotic order picking, in which a robotic arm is equipped with hand-like or suction-cup grippers that can reach into a pick location, grasp an item, and place it into a tote. The backend data input relies on artificial intelligence (AI) to "learn" how to grasp different products, though variation in product sizes and shapes greatly complicates computer programming. Research and development is active in this area—some of the most popular technologies at the ProMat 2019 warehouse automation conference were products that make gains toward order-picking automation, and Amazon has long held an annual competition for precisely this technology. Gripper technology has progressed significantly, and although the robotic arms on which they are mounted have come down in price, the products still are mostly in a development phase.

There are exceptions, however. For example, where products are relatively uniform and arrive at the robotic arm in standardized packaging, such as in The Gap's e-commerce apparel warehouse operation, this automation has proven viable. Yet even in the case of apparel, the technology is not universally practicable, highlighting the variation that will shape technology adoption. As one interviewee, a distribution manager of a mid-sized apparel retailer, pointed out, for a business where the product must look a certain way upon delivery—for example, high-end dresses that need to arrive wrinkle-free—some of the technologies that drop, clasp, or suction goods run counter to the desired end look.

It is important to highlight that the AI that informs the robotic grippers still relies on human intervention. One leading robotic picking machine flags cases in which the gripper cannot determine how to grasp an item, and off-site staff takes over and guides the machine. It's not hard to imagine this manual task—machine learning that relies heavily on human teaching—becoming the purview of dispersed gig workers, blurring the line between warehouse worker and tech worker. AI, in other words, requires intelligence that is not so artificial.

Automated Guided Vehicles

Automated guided vehicles (AGVs) are technology-enabled material moving vehicles, usually a forklift or "tugger," that transport goods along preset routes in a facility. Some are fully automated, while others are a hybrid system that also can be human-operated. Guidance technology has greatly improved—whereas AGVs used to require physical infrastructure in the form of markers in the warehouse, many now use a laser-guidance system, which lowers implementation costs. Nevertheless, AGVs still are relatively expensive and may need to be "caged," or separated physically from workers, which narrows their applicability in warehouse settings.

Sensors

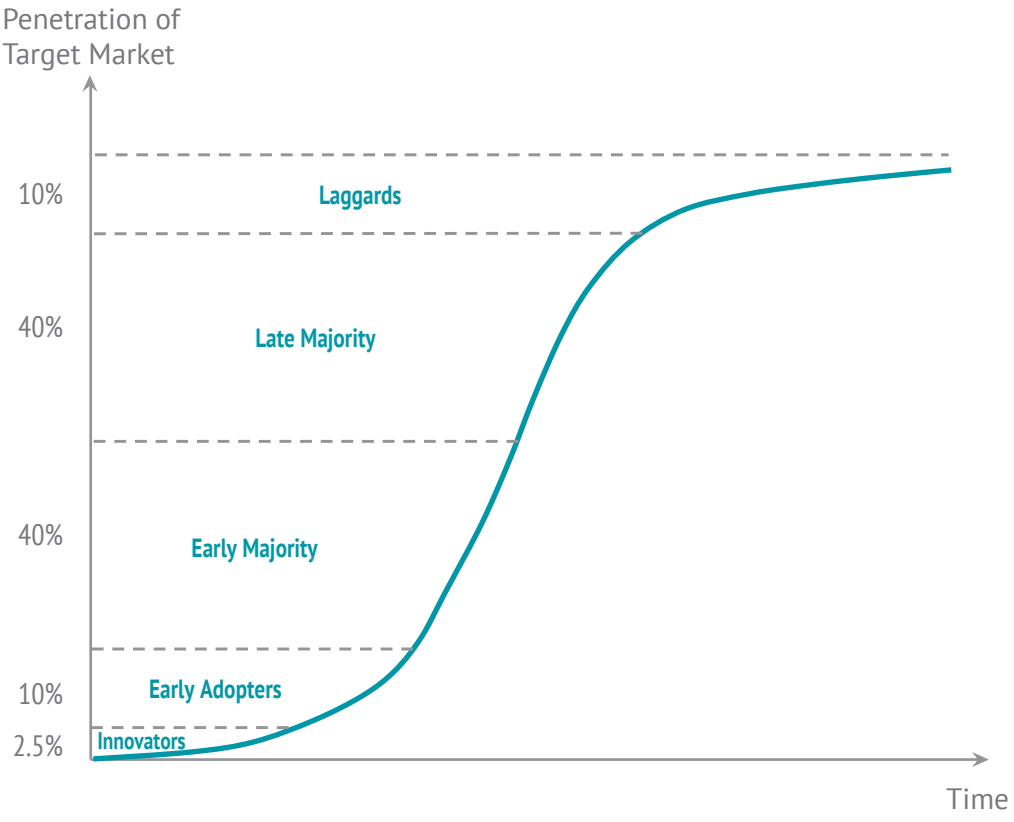
Sensors have many applications in the warehouse, from being able to dynamically track inventory to monitoring the movements of workers to controlling energy usage. Combined with other technologies, sensors can, for example, allow for autonomous palletizers to stack boxes on a pallet by determining the dimensions and proper stacking order. The Internet of Things (IoT), where vehicles, devices, or goods are embedded with sensors that can communicate automatically with each other, is seen to have significant potential to capture real-time data across the logistics system.

The wide range of innovations speaks to the potential opportunity for technology to be applied across warehouse activities. Depending on the source—trade literature, interviews with industry insiders, or technology developers—reports on the state of uptake among leading technologies vary. For example, two different surveys, conducted by Honeywell and the Warehousing Education and Research Council (WERC) three years apart, estimate that voice-directed picking is in use in 12% and 25% of facilities, respectively.[40] There is no shortage of new technologies available to warehouses—the question is how firms make choices about techno-strategy.

Technology Diffusion in Warehousing

In his landmark study of the diffusion of innovations, Rogers[41] highlighted the role that complex social structures play in shaping the pathways of technology adoption. The extent and rate of adoption in an industry is related to multiple factors; chief among them is the relative advantages conferred by new technologies, the complexity of technology implementation, and the compatibility of a given technology with users' norms and systems. These factors help account for the marked unevenness of innovation adoption across a sector. The path of adoption of a given technological innovation most typically resembles an S-shaped curve, progressing from an innovator to early adopters to late adopters (the period in which the rate of innovation adoption slows; see Figure 4.1.). The warehousing industry appears to be in the lower left quadrant of the model, an industry just beginning the process of technology diffusion.

FIGURE 4.1
Diffusion of Innovation, Based on Rogers (1962)



Warehousing currently exhibits a highly uneven landscape of technological adoption. As will be elaborated below, despite several push factors that encourage warehouse operators to explore the use of new technologies, the uncertainties of future demand and questions regarding systems scalability, as well as (paradoxically, perhaps) the sheer pace of technological change,

have inhibited widespread implementation of costly automation systems. For many low-tech warehouse operators, increasing order volumes instead are met through evolving workforce strategies (e.g., adding new shifts, increasing overtime) rather than through mechanization and automation. As long as workers' wages remain relatively low, many warehouse managers will opt to delay investments in new systems, especially given that the implementation of automated systems introduces new complexities into established operations. In addition, the fixed architectures of warehouse facilities and their distribution systems raise questions of whether existing facilities actually are compatible with some new technologies, which in many cases serves to limit the introduction of automation to the piecemeal adoption of technologies that can enhance worker productivity rather than eliminate the need for human labor.

The Context for Technology Uptake

This section analyzes the conditions surrounding firms' consideration of new technologies. As noted above, the context within which warehouse operators make decisions about whether to deploy new technologies includes both push factors and constraints (Table 4.1.). The push factors might lead to increased interest in technological innovation, whereas constraints might decelerate the exploration process. Like decision making about technological uptake, these contextual dimensions do not operate as linear processes, nor do they create inevitable outcomes. The most influential push factors include *labor conditions*, *real estate costs,* and *increasing speed requirements*, while the most common constraints involve *variability and unpredictability*, *outsourcing dynamics*, *inertia*, and the *state of technological innovation*.

TABLE 4.1
Push Factors and Constraints for Technology Uptake in the Warehousing Industry

Context for Technology Uptake	
Push Factors	**Constraints**
Labor conditions	Variability
Rising real estate costs	Outsourcing
Increasing speed requirements	Inertia
	State of Technology

Push Factors

Labor Conditions

The most commonly cited problem warehouse operators encounter today is securing an adequate workforce, because of tight labor markets and Amazon. With unemployment at its lowest rate in nearly a half-century—3.5% in September 2019—the pool of available workers has dwindled. In a 2017 industry survey, 90% of warehouse operator respondents said they were struggling to hire

hourly workers.[42] Compounding low labor availability is the reality that warehouse jobs are rarely work of first choice, given the manual nature of many of the activities.

While the so-called "Amazon effect" sometimes is exaggerated, the fact is that Amazon has had considerable impacts both on its direct retail competitors and on the warehousing industry as a whole—especially in the realm of labor markets. Amazon's million-square-foot fulfillment centers employ thousands of workers, and often are co-located with other distribution centers in dense logistics clusters (for example, California's Inland Empire, the Chicago region, and the Lehigh Valley in Pennsylvania all host Amazon fulfillment centers along with myriad other retail and wholesale warehouses). The effects on local hiring dynamics have been significant. Most warehouse operators report having a difficult time finding and retaining workers, but they also indicate that Amazon's tendency to absorb large numbers of workers exacerbates the problem, especially given the generally tight labor markets found in most parts of the country.[43] This problem becomes especially acute during the "peak season," from October to December, when retailers are preparing for holiday and end-of-year shopping. For firms that experience peak-season surges in sales volumes, the demand for workers soars—sometimes doubling from normal staffing levels. Competition between warehouses for peak season hiring can be fierce, and the presence of Amazon intensifies local labor market competition.

> **"AI, in other words, requires intelligence that is not so artificial.**

However, because the industry is constrained by its operating margins, warehouse operators have few avenues through which they can compete for workers. Wage stagnation pervades the industry, and with little scope for raising wages, even during peak periods, warehouse operators have turned to late-career jobseekers, changed shift scheduling, offered small retention bonuses, and implemented other human resources practices that do not substantially increase total wage bills.[44]

Difficulties in resolving these recruitment and retention challenges have spurred warehouse operators to experiment with an array of labor strategies: some have offered improved benefits packages, others have deepened their reliance on temporary staffing agencies to help manage variable labor demand, while still others have sought out "alternative" or previously overlooked labor pools, such as persons with disabilities[45] and older workers.[46] Crucially for the longer-term restructuring of warehouse industry labor markets, many warehouse operators also report that rising worker recruitment costs are prompting the exploration of how new technologies might increase productivity and/or reduce the number of workers required.

Regardless of whether historically tight labor markets are causing a tipping point that is prompting warehouse operators to more seriously consider new technologies, it is clear that

recruiting and retaining workers is a central challenge facing the industry. A critical, unanswered question is how a downturn in the economy might affect firms' posture toward technology adoption as a solution for their labor woes. If the economy weakens and unemployment rises, employers may well find enough relief to slow the process of seeking technological fixes for labor problems, thereby forestalling the need to make costly—and potentially risky—investments in technologies that are changing rapidly.

Rising Real Estate Costs

The three largest costs of running a warehouse are labor, equipment, and real estate; of these, real estate represents the most significant fixed cost. According to commercial real estate firm CBRE, average rents for warehouse space have risen every quarter for the last five years, while the amount of square footage available for rent has declined.[47] Vacancy rates—or the rate of available properties—dipped to a historic low of 4.3% in the third quarter of 2018.[48] Further, e-commerce warehouses require more space than traditional warehouses. According to one study, e-commerce facilities occupy up to three times more square footage than traditional warehouses, due to higher levels of inventory and a wider variety of stock keeping units, or SKUs.[49] As e-commerce expands, the demand for space will continue to increase.[50]

Given the cost sensitivity of warehousing, rising real estate expenditures represent one more strain on the bottom lines of warehouse operators. The cost of commercial property and its availability varies across geographies, but suffice it to say that rising land and facilities costs exacerbate the problem of low margins in warehousing, and they encourage warehouse operators to attempt to curtail variable costs elsewhere.

Increasing Speed Requirements

Warehouse operators are under increasing pressure to move goods quickly and accurately. These pressures are driven by two dynamics. First, "lean logistics" gained popularity as a supply-chain management philosophy in the 1990s, the central goal of which is the elimination of waste. A major outcome of lean logistics programs is that companies hold lower levels of inventory across the supply chain, including at stores, and focus on turning inventory over more quickly. Lower inventory levels in stores, coupled with higher inventory turnover, results in reduced lead times, or the time between when a store replenishment order is placed and the moment it is needed.[51] Warehouses, in turn, have had to increase the speed and frequency of replenishment processes because of shortened timelines, which translates into the need for faster receiving, accelerated picking, and greater throughput. Further, the shift toward stores with smaller real estate footprints and less backroom storage means that the process of fulfilling orders for brick-and-mortar stores entails more small-quantity picking than it has historically, which resembles labor-intensive e-commerce order assembly.

Second, as noted above, e-commerce introduces additional demands for speed along with an entirely new set of labor-intensive warehouse processes.[52] One of the most potent effects of Amazon in the marketplace has been to shape consumer expectations for e-commerce order delivery. Whereas just a few years ago consumers were content for an order to arrive in three or four days, the delivery window has been steadily narrowing. Interviewees cited Amazon, and its Prime subscription in particular, as the driving force behind shorter package delivery times. To meet service-level agreements, many online orders must be filled within just hours of receipt. The standard timeframe in which customers expect to receive their orders, which is being set by Amazon's sophisticated logistics network, is two days and becoming shorter, as Amazon has introduced next-day and even same-day delivery windows.

At the same time, the Prime subscription has conditioned consumers to expect shipping to be free, or at very low cost. The same is true for order returns. Rising consumer expectations coupled with falling revenues for shipping has forced many companies, even those not directly competing with Amazon, to rethink their shipping policies and distribution strategies, including how technology could increase efficiency and curb logistics costs.

Constraints

Alongside the push factors listed above are a set of constraints and challenges that shape whether, and how, technologies become viable in particular facilities. These involve *variability and unpredictability*, *outsourcing dynamics*, *inertia*, and the *state of technological innovation*.

Variability and Unpredictability

Variability is a fact of life in distribution centers. Natural disasters delay shipments and new sales promotions send orders suddenly skyrocketing. Seasonal peaks, particularly during the months leading up to the year-end holidays, require considerable scalability as certain distribution centers see their throughput soar (especially for those servicing retailers). This dynamic has long challenged warehouse operators to find ways to staff for the busiest days of the year without sacrificing efficiency, and employers often turn to temporary staffing agencies to supply additional labor.

Supply-chain volatility existed before the rise of e-commerce—after all, store shelves have always required restocking based on varying consumer purchasing patterns, and businesses have always needed goods to arrive on time. But direct-to-consumer fulfillment adds to the complexity of scalable operations.[53] E-commerce tends to be highly unpredictable, though more or less so depending on the product segment, and the synchronizing, sequencing, and staging of orders based on the urgency and physical location of the product requires greater agility on the part of warehouse operators. In addition, the precise amount of year-over-year growth in e-commerce is difficult to predict; "It's a nightmare," in the words of one interviewee. For e-commerce and traditional fulfillment alike, the ability to forecast demand has been the Achilles heel of

efficient operations. Another interviewee, a senior supply-chain consultant, expressed it this way: "Companies have had inaccurate forecasts for so long, the catchphrase 'the forecast is always wrong' has become adopted within the culture, and people just accept the fact it's going to be wrong."

Until recently, the forms of automation available to distribution centers tended to be inflexible and difficult to scale. A conveyor system, for example, cannot hold more goods or run faster. For this reason, during peak periods an operator might add an extra shift to accommodate fluctuations, though this presents its own challenges in terms of staffing and worker recruitment. One interviewee with a 10-fold increase in holiday shopping volumes reported that his facility would switch to a highly manual process during peak season and hire hundreds of extra workers because the conveyor system simply could not accommodate the influx of orders. The workaround was to abandon the existing mechanized system and instead add to the workforce in order to contend with the sharp increase in order volumes.

Outsourcing

Outsourcing in logistics is pervasive, and according to some estimates, on the rise; in a recent survey, 58% of companies reported they were planning to increase outsourcing of logistics operations, compared with 27% planning to in-source these activities.[54] Outsourcing has its downside, however, and, most relevant to this topic, it can create strong disincentives to investing in new technology. There is a fundamental hurdle to overcome: firms historically have tended to outsource the most repetitive and transactional activities to 3PLs, and these also are some of the priority activities for automation. Instead of outsourcing, firms could choose instead to keep warehouse activities in house and adopt new, labor-saving technologies. 3PL contracts often are short (three to five years), which makes a return on investment difficult to achieve in that timeframe for warehouse operators undertaking major capital and technological investments.[55] Combined with the ever-present risk that technological investments made for one client may not be transferable to others, the technologies that would reduce staffing levels significantly often are beyond the reach of most 3PLs, especially those operating small and mid-sized facilities. The primary exception to this is the very largest 3PL companies, which are actively experimenting with new technologies, attempting to position themselves in a technical assistance role with a set of workable technologies on hand for clients, thus modifying their value proposition.

Inertia

The ways in which warehouses historically have been organized and operated can be difficult to alter, creating organizational inertia that can constrain the scope of technological change. First, existing systems of mechanization, such as industrial conveyors, required major capital investments to install, and companies understandably would like to use them as long as possible. In some cases, this means applying technologies to processes around the mechanized system or simply relying on existing technologies longer, even where newer options offer significant

efficiency gains. For most warehouse operators, operational inertia will limit the extent of technology adoption, at least in the short run.

Second, resistance to or lack of capacity for change within facilities can contribute to low levels of sophistication, in many forms. The primary way in which these constraints slow technological advances is that the most potentially powerful technologies require high-quality input data, which many companies are not collecting. A vice president at a large 3PL explained what he has been seeing in terms of clients' data sophistication: "You can't have artificial intelligence or leverage new technologies if you've got crummy data. So we see … a digital divide emerging, between those [companies] that make the investments in systems and process management to ultimately have good and consistent data, and those that end up on the still-viable, but more basic, end of the spectrum."

Even those companies that have made substantial investments in technology may not be collecting and using data opportunistically. One interviewee, the head industrial engineer at a mid-size retailer that invested heavily in automated goods-to-person technology, reported that the company still lags behind in its data systems: "We don't use our information to be more proactive with our decisions. We still wait to visually see something, as opposed to using the data and the software to help us make better decisions quicker." The persistence of older methods of operating warehouses presents barriers to collecting and analyzing the data required to implement new technologies, or improve planning and execution.

State of Technological Advancement

Finally, the rate at which new technologies are being developed complicates decisions about when exactly a warehouse operator should invest in new systems, and which systems should be implemented. Some promising technologies have not yet reached the point where they can be reliably deployed in a live warehouse setting. Three examples from interviews are illustrative:

- The most advanced order-picking robots still are operating far below the precision level necessary for widespread use. According to an interviewee, "It's still hard to ask a robot to go to a shelf and identify and grab an item. The current breed of picking robots work with 60–70% accuracy, and warehouses need to operate at 99.9% accuracy."
- Robots still lack the intuition that, for example, allows a human forklift driver to calculate that in a situation in which there is high wind, a high stack, and low weight, the stack of boxes is likely to fall down—and intervene before it does so.
- Depending on the assortment of goods in a facility, robots are not adaptable to varying product profiles. As one interviewee, a warehouse manager, explained, "I struggle to find the robot that will be able to handle a bag of plaster of Paris, a bit for a jackhammer, a galvanized steel garbage can, a saw blade, and a five-gallon bucket of paint. Oh, by the way, what happens when that [plaster of Paris] bag ruptures? How does the robot know that the bag is ruptured?"

In some cases, combinations of different, mature technologies will be required in order for performance to reach the level of humans. To be sure, the research and development of these solutions is under way, but it is impossible to predict when they will converge in a way that substantially changes the landscape of adoption. Each year, available technologies become better and, in most cases, cheaper, but even these trends can convince companies to put off making investments, biding their time in order to take advantage of future product iterations or price cuts on existing technologies.

> **"I struggle to find the robot that will be able to handle a bag of plaster of Paris, a bit for a jackhammer, a galvanized steel garbage can, a saw blade, and a five-gallon bucket of paint."**

A further complicating factor is that many technology startups are seeking to be acquired by more established firms, raising questions about the support of the product or service over the long run. The trajectory of Kiva Systems serves as a warning: after purchasing the company in 2012, Amazon discontinued support for existing owners of Kiva robots in 2019, and those companies are now left with obsolete technology. As one interviewee—whose company had firsthand experience with Kiva's robotic fulfillment systems—said, "Even if you [find] a startup that you think is perfect, you have to go in realizing it may be something else within five years."

Taken together, the push factors are, at the very least, leading to increased interest on the part of warehouse operators in pursuing technologies that help ease the demands for workers, rising real estate costs, and increasing order velocity. On the other hand, the constraint factors create obstacles to technological adoption that likely will moderate the speed of uptake. The ways in which each of these factors unfolds in companies helps determine the path and rate of technological change, and are difficult to account for in aggregate estimates of automation and its impacts on warehouse industry employment.

SECTION FIVE:
Technology Meets Shifting Industry Dynamics

This section presents analysis of the nexus of technology and the particular dynamics of the warehousing industry, based on interviews and other research conducted for this report. The first two findings refer to the current state of the industry—how the industrywide economic structure shapes techno-strategies, and how e-commerce is driving the leading edge of innovation. The second two findings present likely future impacts of technology adoption across the industry, absent major shifts in the economy due to recessions or other major disturbances.

1. The cost-sensitive economics of the industry are key to understanding firms' orientation toward technological adoption.

Section 2 reviewed the economic structure of warehousing: it is characterized by thin margins and cost-based competition and, at the same time, responsible for managing high levels of volatility and risk. Low margins can leave little room for investment in new technologies, despite the potential for efficiency gains. Outsourcing is one mechanism through which firms have tried to manage these dynamics, but contracting to a 3PL appears to complicate technology uptake (see further discussion below).

Broadly speaking, warehouse operators have moved cautiously into potentially risky experiments with new technologies, relying instead on experimentation within workforce systems and on streamlining existing processes. These trends likely will continue—the cost sensitivity of the dominant business model will moderate the rate of technological experimentation and uptake,

though some firms will find first-mover advantages a worthwhile prospect. Absent a major shift in how warehousing activities are valued by lead firms, the dynamics that have created barriers to innovation and contributed to the industry's status as a technological laggard are likely to persist over the coming five to 10 years.

2. E-commerce is driving experimentation with new technologies.

The rise of online shopping has had major repercussions on the warehousing industry. E-commerce order picking requires more labor and the order fulfillment process is accelerated, given consumers' delivery expectations. Additionally, Amazon's influence in the online retail arena is significant, particularly in the context of the company's promises of increasingly faster delivery.[56]

The combination of labor-intensive order picking and the speed with which orders must be shipped has made e-commerce a leading driver of growth in warehousing employment and, interviewees report, has led to increasing interest in technologies to support the order-fulfillment process. With a fixed amount of space within a facility, warehouse operators are limited in the number of workers they can add before congestion creates inefficiencies. Further, in the context of a tight labor market, employers seek to ease their reliance on workers, where possible. Each picking requires a larger workforce, yet the complexity of the process and the limited availability of technologies for nonroutine aspects of the job make automation more difficult. However, because the likelihood that a given facility will adopt new technologies is related to the desire to reduce labor costs, it stands to reason that facilities with large numbers of order-picking workers likely would seek to become technological first movers. These enterprises likely will be leading experimenters and, if proven successful, innovations will diffuse to other operators.

Technological adoption has enabled the rapid expansion of e-commerce, as well as sharp increases in warehousing employment. The long-run impacts of technological change on employment, therefore, must be closely parsed; the warehousing industry likely will experience secular growth for the foreseeable future. At the same time, certain occupations or facilities may experience significant job losses due to automation, as e-commerce facilities lead the way in experimenting with and adopting labor-saving technologies.

3. Technology uptake will be uneven.

It appears that variation will be a key feature of technological change and automation in warehousing. Many factors shape the tendency for uneven technology uptake, and the circulation of ideas and innovations is propelled by a constellation of economic, social, and political forces. There are three main elements to this variation: *unevenness across firms*, *unevenness within firms*, and *unevenness across technologies*.

Across firms, there are significant differences in approaches to seeking new technologies for warehouse operations. Two main factors help explain these divergences: the profile of the business, including the specific activities occurring in warehouse facilities, and the culture of the organization. A technology may make good economic sense, but not social sense, to an organization.

The first movers in technology adoption likely will be major retailers: firms with a large number of SKUs (500,000–1 million), high throughput, and that perform at least some of their own warehousing. The warehouse facilities that store and distribute these goods are large, employ hundreds or thousands of workers, and run multiple shifts. Those with a high volume of online orders likely will automate e-commerce fulfillment first, even if it's only that section of the operation. Finally, the product market(s) in which a firm is competing (e.g., apparel, pharmaceuticals, cosmetics) and, in particular, the techno-strategies of the firm's competitors, will shape the uneven landscape of uptake.

It's clear that warehouse operators are in disparate stages in their techno-strategy development, and the majority of firms are moving cautiously into automation. A senior executive at a leading 3PL offered this reflection on the uneven landscape of technology adoption: "Everybody's not on the same lap in an eight-lap race. When you talk about e-commerce, oftentimes we find [customers are] in completely different places." His remark suggests that even in the e-commerce realm, where there is the most widespread and enthusiastic interest in automation, companies are taking very different approaches. This is particularly true when comparing retailers with consumer packaged goods (CPG) producers, durable goods manufacturers, and 3PLs, where the former tends to be more advanced. One interviewee, a vice president at a large 3PL, offered this illustration of unevenness among firms: "I can go into one customer, take them an RF [scanning] gun, and they just think that's the most innovative thing they've ever seen; whereas the other customer wants drones running around the warehouse. People's definition of innovation is very different, and where they are in their maturity cycle of being able to adopt that innovation is very different."

"It's clear that warehouse operators are in disparate stages in their techno-strategy development, and the majority of firms are moving cautiously into automation.

One indication of the unevenness of technology adoption in the industry is evident in the market penetration of warehouse management systems (WMS). WMS software, which tracks inventory and coordinates order processing for a facility, is the most common technology across the warehousing industry. Yet according to a recent study, 33% of warehouses do not use one.[57] Operating a WMS is widely considered to be a fundamental building block for the adoption of other technologies, and the study authors estimate that at least one-third of warehouses in the

United States continue to operate using spreadsheets and paper, without an urgent aspiration to consider technologies that would integrate with the WMS.

Included in the two-thirds of warehouses that *do* use a WMS are those that have not upgraded their system for many years—recall that in many cases, the first WMS software was proprietary and developed in house. Consider the reflection offered by a 3PL vice president:

> *What shocks me [is] when we go into some of these big Fortune 100 [companies], and you see them running warehouse management systems that are 30 years old, and you just [ask], "How are you surviving?" To think about putting robotics into a facility where they're running a 30-year-old version of a WMS is just not feasible.*

WMS adoption is one illustrative example of the uneven landscape and slow uptake of technologies in this industry, but the dynamic is not limited to software innovation. Long-available hardware similarly has had a slow adoption process, which speaks to the cautionary approach that pervades the industry. There are few indications this conservative posture will shift substantially in the near term.

Within firms, there is a range of activities that potentially could be targeted for the application of technology or automation. But firms must make choices about which processes should be prioritized, leading to a variegated landscape of technological sophistication across activities in a warehouse. Even firms at or near the leading edge of innovation in one area often lag behind in other areas. For example, a large parcel company had made massive investments in a state-of-the-art, high-throughput conveyor and automated RF scanning system, but managers still were using spreadsheets, a whiteboard, and countless staff hours to schedule workers to handle fluctuating package volumes.

Finally, *across technologies* there has been highly uneven uptake, in large part because the technologies tend to be specialized to the process for which they are designed. In addition, the political economy of technology development influences which viable product emerges as the market leader. A major obstacle for developers of new technologies is proving the products actually work in a live warehouse environment. Doing so requires convincing a warehouse operator to pilot a technology, which can be disruptive to the normal flow of operations. Yet, without a pilot phase, technologies lack the credibility needed to gain widespread acceptance.

New models of modularity and asset ownership may reduce barriers to adopting some technologies. Two key features set apart some of today's leading technological solutions from those of the past: modularity and leasing programs. Most prominent in the autonomous mobile robot (AMR) space, modular systems allow users to scale their use of AMRs to respond to fluctuating business cycles, adding robots as demand grows year seasonally or over time.

Modularity addresses central problems of past technological advances: it can reduce the initial capital outlay required, putting automation within reach of a new set of market actors, including

small and mid-sized firms and 3PLs. It also allows warehouse operators to increase capacity during high-volume periods and then scale back as demand falls. The latter approach historically has been addressed by adding seasonal labor, often through temporary staffing agencies. During the peak season, when many firms would wish to increase the number of robots in use, larger warehouse operators might be able to leverage their size to access additional robots more easily, potentially leaving smaller firms without the capacity to meet order volumes.

Robot leasing programs have been used in the manufacturing sector for years, but the so-called "robots-as-a-service" (RaaS) model is a more recent arrival to logistics. Companies rent the robots, paying by the amount of time used or per transaction, and thereby reduce the risk of obsolescence. The leasing entity retains responsibility for remote monitoring and maintenance of the robots.

"Even in cases where the activities occurring in a facility have a corresponding technological solution, and that solution is economically feasible for the enterprise, there will be significant divergences among firms in their adoption of new technologies.

Taken together, these two features may be game changers—but only for those facilities in which modular, RaaS robots make sense. One interviewee, a vice president of a large 3PL, summed it up this way: "Newer, more flexible automation changes things: you can move it around between operations, and you're leasing the equipment. You can think of [automation] differently, especially if it's a technology where we have other sites where the technology could fit in."

In short, these factors suggest that even in cases where the activities occurring in a facility have a corresponding technological solution, and that solution is economically feasible for the enterprise, there will be significant divergences among firms in their adoption of new technologies. It is this fact that complicates aggregate reports of technological change and forecasted impacts on jobs and workers. The unevenness is partly what makes predicting technological change so difficult.

That said, identifying leading firms, the latest processes, and cutting-edge technologies can help industry leaders and policy makers anticipate the effects of new technologies on jobs and workers. Across firms, it is important to understand which companies might be early adopters, and thus which workers likely will face the initial impacts of technology implementation. In the same vein, firms that choose to delay or not to adopt new technologies will have to find other ways to compete, which likely will have effects on the organization of work in these facilities. Within firms, all things equal, it is high-priority processes, and the occupations involved in these processes, that will be affected first. And across technologies, tracking the products that are gaining attention and investment may be a predictor of emerging frontrunners and their specific impacts on jobs and workers.

4. Technology will have potentially large impacts on 3PLs and outsourcing in the warehousing industry.

Outsourcing is a significant trend in the warehousing sector, and the introduction of new technological capabilities undoubtedly will shift the landscape of subcontracting. This applies to the prevalent practices of both 3PL outsourcing and labor outsourcing to temporary staffing agencies.

3PL Outsourcing

Some interviewees noted a recent trend of companies that are new to e-commerce outsourcing their fulfillment to 3PLs. The motivation behind outsourcing is that companies newer to e-commerce have neither the logistics infrastructure nor a reliable estimate of demand—that is, the ability to forecast volumes is difficult for most internet shopping operations, but particularly so for those just launching an e-commerce channel without brick-and-mortar stores. Some of these companies have the intention to bring e-commerce fulfillment in house once a more accurate forecast of order volumes emerges. But, overall, 3PLs likely will continue to benefit from the expansion of e-commerce.[58]

Yet, even as e-commerce has the potential to expand the use of 3PLs, the extent of warehouse outsourcing complicates the landscape of potential technological uptake. On one hand, there are strong disincentives for 3PLs to invest in new technologies—short contracts (generally three to five years, though interviewees suggested that their customers now are seeking even shorter contract terms) and cost-based competition are among the biggest. Many 3PLs have avoided investments in new technology because of the possibility of losing the customer at the end of the contract, which could make any investment obsolete. Short contracts also make it difficult to recover the costs of the initial investment.

Despite these disincentives, there is evidence that larger 3PLs regard technology as a key differentiator in the increasingly crowded contractor market. 3PLs are piloting robotics products in live warehouse environments, gaining expertise in emerging software and hardware solutions, and trying to carve out a role as technical assistance providers for customers. If successful, these strategies could increase barriers to entry in the 3PL market. The history of outsourced warehousing, however, suggests such higher value-added activities are rarely the driving force behind contracting decisions; in fact, as 3PLs have tried to move their customers up the value curve, most have met resistance.

Of course, some lead firms have bucked the outsourcing trend and kept their warehousing operations in house. For those that seek out outsourcing options, there appear to be three possible scenarios for the changing role of warehouse outsourcing:

- **Scenario 1:** Lead firms use 3PLs with little automation for less efficient, lower value-added activities (e.g., nonconveyable products like canoes) and, where applicable, retain the more efficient processes in house with increasing levels of technology. It's conceivable the market of smaller 3PLs that are laggards in technology adoption increasingly may be matched with customers that also are lagging. This, in turn, may lead to worsening working conditions—smaller contractor firms are more likely to violate labor laws out of ignorance, lack of staff capacity, or in order to pad thin margins.[59]

- **Scenario 2:** Lead firms seek out 3PLs that are adept with technology to learn about, identify, and implement systems appropriate to their business. Large 3PLs, like DHL and XPO, are actively piloting different technologies to better understand the kinds of operations for which each is appropriate. When a customer is interested in applying a new technology to a warehouse process, the 3PL helps them understand their options. Any customer-3PL relationship that involves technological innovation would benefit from longer contract terms, ideally more than five years.

- **Scenario 3:** Lead firms use 3PLs to run lead firm-owned facilities and technologies. As one interviewee explained, "The fully automated warehouses that I've been in are all customer-owned facilities. They may contract with a 3PL to run it, but that's just a pure labor play for that 3PL." Data from interviews and secondary sources suggest that firms are more likely to invest in technology tailored to their operations, but lead firms still could choose to outsource the management of these facilities to 3PLs.

3PLs also are experimenting with new organizational configurations and models of collaboration. One interviewee, the president of a midsized 3PL, said his company is exploring how it might commingle smaller e-commerce startups in a single facility and implement automation across all of them. Each startup on its own may have low volume, but by combining their operations, they each could experience faster fulfillment and benefit from "the automation effect." The task of finding customers whose products, processes, and desired location are complementary might be daunting, but the intent is to allow smaller companies to compete in e-commerce markets at a lower cost.

New models of collaboration take different forms, though central to them is leveraging excess warehouse capacity. For example, the MonarchFX Alliance brings together large 3PL providers, some of whom are direct competitors, with proprietary robotics, inventory and distributed order management, and other technologies—all in an effort to offer customers a logistics infrastructure that can compete with Amazon. Emerging collaborations among 3PLs indicate the exigency of implementing cost-effective technologies in the context of subcontracted operations.

Labor Outsourcing

Temporary staffing is a common workforce strategy pursued by warehouse operators. The industry insiders interviewed for this research offered mixed arguments about the relationship between the adoption of new technologies and the deployment of temporary labor. Discussions centered on three issues:

- If firms don't use new technologies, such as autonomous mobile robots, they'll have to rely more heavily on agency-supplied temporary workers.
- Autonomous mobile robots may increase reliance on temps because automation enhances operators' ability to further de-skill core warehousing processes.
- Firms do not necessarily expect to reduce the need for seasonal labor through automation during the peak season.

Given the industry's cost constraints, temporary staffing agencies likely will remain a key means through which warehouse operators hold down labor costs. Further, new platforms for procuring temporary labor that promise to reduce the friction of finding workers are emerging. Similar to other forms of "gig" work, platforms like Wonolo aim to smooth labor supply and demand matching using algorithms. The potential expansion of temporary staffing arrangements, coupled with well-documented wage differentials between temporary and direct-hire workers, suggests that deleterious conditions could be on the horizon.

3PLs and temporary staffing agencies alike are navigating an uncertain landscape of change with different competitive strategies. Some are exploring new roles that leverage technology, while others appear to be taking a wait-and-see approach without significantly altering their value propositions. The structure of outsourcing, especially 3PL contract terms, constrains the options for 3PLs as they consider new technologies, and technological uptake among 3PLs has the potential to shift the contracting market in a number of ways. The trajectory of this change is, as yet, unclear, but will be shaped by the dynamics of unevenness prevalent across the industry.

SECTION SIX:
Impacts on Tasks, Jobs, and Workers

This section turns to the impacts of new technologies, and the dynamics discussed in Section 5, on tasks, jobs, and workers. Predicting technology's effects on the organization of work is difficult because of the unevenness with which these dynamics are likely to play out. Still, the purpose of this research is to draw on data collected from interviews and secondary sources to analyze unfolding trends and to speculate on potential repercussions, which are detailed below.

1. New technologies are likely to lead to work intensification, especially in each-picking environments.

Most warehouse work is strenuous. It entails manual processes that rely on strength and stamina, which takes a physical and mental toll on workers. It is possible in some cases that the priority tasks to be reorganized through technology adoption represent the most grueling aspects of the job. For example, removing walking or reducing the amount of lifting and twisting that workers must perform could offer significant ergonomic improvements and diminish the stress on workers' bodies. This research suggests, however, that even though some technologies promise to alleviate the need for the most arduous activities, this will be coupled with attempts to increase the pace of work and productivity in other tasks, with new methods of motivating and monitoring workers.

High-Priority Process: Each Picking

Warehouse workers' jobs include various tasks, some of which are higher priority for technological applications than others. First-order targets often are those that are the most labor-intensive and/or contribute the least amount of value to the final product. As was

discussed in Section 5, the highest priority in the short term is to apply labor-saving technologies to high-volume e-commerce order picking (and, because of the similarities of the process, frequent, small-batch replenishments to retail stores that hold limited inventory). The labor-intensive nature of picking individual items to assemble orders—so-called "each picking"—requires large numbers of workers, so warehouse operators place great value on reducing headcount or increasing throughput by reorganizing this activity. Workers involved in each picking likely will see significant impacts on the content and quality of their jobs, due to the introduction of software and hardware applications to particular subtasks, though only some of the process is automatable given current technologies.

There are three key areas in which technologies are changing the each-picking process: order-assembly planning, machine-directed picking, and goods-to-person picking.

Order-Assembly Planning

The process of planning order picking can be organized in one of three ways, which are dispatched by WMS software: discrete, batch, and waveless picking.

- With *discrete order picking*, all of the items for an order are picked at once and packaged. This process requires the most walking, since items might not be located near each other, and is thus the least efficient and most taxing on workers.
- *Batch picking* organizes the picking process so that workers select items that are located near each other for multiple orders. The batched items then are divided up and the orders are consolidated across batch picks. Because the orders are batched based on the proximity of products (i.e., instead of going to the same slot multiple times for an item, all the orders containing that item are batched together and picked at once), the picking sequencing is critical to efficiency. The complexity of this sequencing makes it more difficult to handle urgent orders—for example, a next-day delivery that needs to be picked within an hour of order placement.
- Finally, *waveless picking* was developed to combine the efficiencies of batching orders with the flexibility of adding new, high-velocity orders into the process without interrupting the flow of goods. Many of the leading WMS systems now have the capability to do waveless orders, and for high-volume e-commerce fulfillment, waveless picking is essential.

At first blush, the picking process appears to be a seamless, finely tuned activity. Yet interviewees conceded it is common for too much work to be released into a warehouse at a given time, leading to congestion at chokepoints in the order-assembly process. Congestion, in turn, lowers productivity, a problem that is out of workers' control yet nevertheless impacts them. The picking process is a promising application for AI, which optimizes the flow of goods and people and, through machine learning, determines over time how to release orders more efficiently into the warehouse. As increasingly sophisticated AI enhances the planning process, workers may find

their jobs improved somewhat. In the meantime, until they are resolved, glitches in the process of releasing orders will continue to impact workers.

Machine-Directed and Goods-to-Person Picking

The hardware that might accompany the picking processes detailed above varies widely in terms of its technological sophistication, and the most prominent among them are largely labor complementing rather than labor substituting. Machine-directed picking systems replace paper pick lists with tech-enabled labor deployment, reduce walking, and serve to constantly orient workers toward their productivity rate. At the lower-tech end of the spectrum, a facility might implement voice-directed picking, in which a warehouse worker is directed to a pick location through a headset. Vision-directed picking, which uses virtual reality glasses to guide workers, is the next wave of innovation, though it is not widely in use given the cost of virtual reality glasses. Some autonomous mobile robots virtually tether a worker to a cart, keeping the worker at defined walking and picking speeds, always engaged with the technology and picking process, with constant feedback on their performance. Others are designed to shuttle goods between areas of the warehouse, again reducing walking and pacing the picking or packing rate. Goods-to-person systems deliver products to a workstation, which can offer a more ergonomic work environment while removing walking.

The common thread among technologies that address each picking is reducing low value-added activities coupled with the ceaseless reinforcement of workers' focus on their effort and efficiency. This research suggests that the main impact on workers as the content of their duties changes likely will be work intensification. Heightened pressures on workers occurs through twin processes.

> **"The assumption that streamlining processes leads in a linear fashion to greater efficiencies, and thus cost reductions, may be fundamentally flawed.**

The first constrains human interaction with co-workers. Linking workers to machine-directed order picking or goods-to-person systems effectively removes the opportunity for workers to interact with one other, even in cases where they might be helping one another perform tasks or solve problems.

The second process enables the micromanagement of work tasks at an unprecedented scale. Many new technologies applied to the picking process utilize algorithms that govern the sequencing of order assembly and picking rate. Algorithms track, analyze, and inform workers about their performance, measured against engineered labor standards as well as the performance of co-workers. Engineered labor standards, along with algorithmic management, point to what some have called "digital Taylorism," or scientific workforce management amplified by an order of magnitude. The time and motion studies that are conducted by engineers now are beginning to be augmented by machine

learning and data captured by new technologies, such as sensors that track the time it takes a worker to reach a pick location, scan a label, select a product, and place it in a bin. This data has the potential to increase pressure to work quickly, and in the context of the low margins that characterize this industry, productivity becomes paramount and improvements are focused on reducing cost.

Digital Taylorism is well under way in some parts of the warehousing industry. Amazon has attracted significant attention for the productivity rates the company expects of order pickers, and recent media reports detail the difficulty some workers have as they attempt to "make rate."[60] Careful tracking of productivity has led to termination when employees are not reaching the target rate, and workers report feeling anxiety about the possibility of being terminated.[61] In order to incentivize workers to maintain high productivity rates, Amazon introduced MissionRacer, a video game that pits workers against one another as they pick customers' orders.[62] The gamification of warehouse work is thus far limited, but is garnering increasing interest among warehouse operators seeking new ways to motivate workers.[63] While there is some evidence that gamification can ease the monotony of repetitive work, it also highlights the potentially nefarious impacts of competition on both workplace culture, and worker health and safety.[64]

Rising productivity requirements also raise questions about the limits of the human body, and there are concerns that such close scrutiny over workers' movements could have detrimental psychological impacts. The assumption that streamlining processes leads in a linear fashion to greater efficiencies, and thus cost reductions, may be fundamentally flawed. Gains could be counteracted by new health and safety hazards, as well as increased employee turnover due to overwork and burnout. The toll on workers is both physical and psychological, as increased performance metrics may push workers to exhaustion while heightening anxieties over the threat of being dismissed for missing performance targets. The unintended consequences of work intensification, therefore, could aggravate the challenge of recruiting and retaining workers, especially in tight labor markets.

2. New technologies have the potential to de-skill some jobs.

Most warehouse occupations call for a high school diploma or less. In terms of skills, forklift drivers require training and certification, which often can be completed onsite. Shipping and receiving clerks may need some computer skills, depending on the processes in place. The required level of training and educational attainment, however, belies some warehouse-specific experience and skills that can improve workers' performance. For example, the commonly used RF scan guns have a small screen and a set of commands and keys that are not intuitive; and the layout of warehouses, including aisle or slot numbering, can be confusing to a newcomer.

Some technologies explicitly endeavor to simplify aspects of warehouse work. Kiva was one of the first technologies to focus on de-skilling. As one interviewee, whose retail company had purchased the Kiva system, noted, "[Kiva] was definitely [geared toward] job simplification, for the most part. Compared to using an RF scanner [where] you've got all these menu options, the Kiva was very simple, so you can hire temporary labor to fill in and be productive in a short period of time. That was a benefit, being able to shorten the training times."

Other technology developers have followed suit. One such project explicitly markets their follow-me AMR, Chuck, as a way to simplify the picking process through a "fully directed workflow": it leads workers across the warehouse, pacing them as they walk and pick, and streamlines the process of order selection. The shortened training time and simplified interface helps to reduce employee turnover costs and, as the technology company CEO stated at an industry conference, allows employers to rely more heavily on temporary staffing. De-skilling often puts downward pressure on wages and may facilitate the use of temporary workers. For workers, this may lead to wage stagnation and increases in job insecurity.

Other Processes Subject to Possible De-skilling

Beyond the each-picking order-assembly process, the content of other warehouse activities could be de-skilled in the near future. The system for receiving a truckload of goods into a warehouse involves multiple processes that are targets for AI. Shipping and receiving clerks verify that the goods on an inbound truck match what the vendor reportedly sent, and manage inbound and outbound documentation and allocation—a time-consuming process. For one interviewee's company, a home improvement retailer, this task became a priority for automation, since much of it is repetitive and routine. "Almost all of our paperwork is now automated. It's not as sexy as robots driving forklifts, but the reduction in workforce was eight or nine people across all the shifts." Other interviewees echoed the eagerness for automating parts of the receiving process and the subsequent reduction in headcount such automation enables.

The application of AI to shipping and receiving tasks is gaining traction, especially at a time when inventory accuracy—knowing exactly how much product is on hand at any given moment—is becoming increasingly important. AI has many additional warehouse applications, including capturing and analyzing data on equipment utilization, slotting goods within the warehouse, and issuing pallet-building instructions, and the WMS is the most likely place for the AI to reside. All of these applications have the potential to shift decision-making tasks away from workers and reduce the skill content of certain positions. It's possible that companies will invest in software and AI applications in order to forgo the expense of making large capital investments, instead using more cost-effective software enhancements to gain efficiencies and bide time until lower-cost hardware solutions can be identified. This likely would cause AI-induced de-skilling to occur more quickly than other forms of technological change.

Another occupation at risk of potential de-skilling is forklift drivers. Automated guided vehicles, or AGVs, are designed to replace traditional forklifts. One motivating factor for the use of AGVs is that forklift drivers often are some of the highest-paid nonsupervisory workers because of their specialized skill set. Yet AGVs can cost many times more than a standard forklift, making a satisfactory return on investment at this time difficult to achieve.

While there appears to be significant interest in how AGVs can improve productivity in warehouses, there are complications for the adoption of AGVs. Perhaps the most difficult to reconcile is that precision forklift movements have proven difficult to automate. One possible scenario is for AGVs to move products horizontally across a facility, and for humans to perform the precise vertical movements of placing or removing a pallet. This effectively would divide forklift driving into distinct subtasks, while removing skilled labor from the easier-to-automate activities.

Upskilling vs. Labor Reallocation

While it is possible, in principle, for new technologies to produce upskilling effects in the sector, there is little evidence of this occurring at this time. One example of upskilling could be cases in which robots that augment or replace workers need ongoing maintenance, and companies are able to shift work hours from more-manual, routinized activities to higher-skilled maintenance tasks. However, robots-as-a-service introduces a model in which the responsibility for monitoring and maintaining the robots lies offsite with the leasing entity, rather than the warehouse that uses the equipment. A similar dynamic holds true for robotic picking machines that require human intervention to learn how to grasp particular objects, but these jobs are offsite. In these cases, a pathway from less to more skilled work for workers whose jobs might change or be eliminated by robots is unlikely. Other technologies and ownership models might offer more opportunities for higher-skilled work to remain onsite.

In order for incumbent workers to move from less-skilled to more-skilled labor, training infrastructure is required, either through public-sector workforce development systems or within a company. For example, Amazon has proposed a large program to retrain 100,000 existing workers for higher-skilled technical jobs.[65] Most warehouse operators are unlikely to invest in retraining programs at scale, given the cost constraints of the industry, and thus a more probable outcome than the upskilling of low-skill job functions is limited labor reallocation to other tasks. Interviewees often pointed to the ability to shift workers from menial tasks to those that are less routine and require greater problem solving. At the same time, however, interviewees also conceded that the point of automation is to improve productivity and/or reduce headcount. Labor reallocation in warehousing appears likely to be little more than a provisional stage of technological advance.

3. New technologies are likely to transform how workers are managed.

Algorithmic management introduces new forms of workplace control, where the technological regulation of workers' performance is granular, scalable, and potentially relentless. Capturing worker productivity data has relied largely on widely used RF scan guns, but in the past productivity tended to be calculated at an aggregate level. Newly available products, such as "wearable" warehouse technologies, follow-me carts, and increasingly sophisticated labor management software, allow more granular tracking of workers' movements, including walk speed, routes, bottlenecks, and break time. Coupled with productivity algorithms, these systems can dynamically urge workers to increase speed, and identify efficiency, accuracy, and movements at the individual worker level. At the same time, however, such close monitoring of workers and uncompromising electronic management could corrode working conditions and employee morale.

Worker Monitoring

Sensors and wearable technologies are used to track twisting, bending, walking, and other movements—or breaks—of a worker. Amazon made headlines in 2018 when the company announced patents on a wristband for warehouse workers.[66] The wristbands, developed in the name of greater efficiency, track and guide workers' hands toward product locations by sending feedback to workers when their hand is in close proximity of the pick location. The digital scrutiny necessary to relay such fine-grained spatial information immediately raised questions concerning workers' rights to privacy and the extent of control a company should be able to exert over its employees.

The Amazon patent points to a device that is many steps beyond the current generation of hands-free RF scanners. Other wearable technologies, such as Modjoul's Smart Belt, include sensors that gather location and motion data into a dashboard for analysis and action. Exoskeletons, while not widely used today, would be worn by workers to support parts of the body likely to experience strain or undue exertion.[67] They conceivably could reduce exhaustion for workers, but their value may lie more in the data the devices capture about workers' precise bodily movements as they navigate their job tasks. Data collected from these devices would be invaluable to technology developers seeking fine-grained data inputs for the next generation of robots, while also shifting the ways in which employers manage their workforce.

Technologies such as sensors can collect sensitive data on workers' every move.[68] The data are valuable to warehouse operators, since they monitor worker productivity as well as safety hazards. Yet the same technologies that are augmenting worker movements also are surveilling them. The experience of workers with some new technologies is one of increasing atomization from each

other, removing opportunities for social interaction and on-the-job problem solving. Finally, new technologies are enabling increased worker monitoring and tracking, and the extent of data collection and storage, as well as decisions regarding future use, are not transparent to workers, raising significant privacy concerns.

Scheduling

Another form of algorithmic management is just-in-time scheduling. Well-established in other sectors, most notably retail, scheduling software like Kronos allows managers to dynamically flex workforce size up and down. For workers, algorithmic scheduling has led to greater insecurity in their work hours, leaving some to be essentially "on call" for their employer with no guarantee of being assigned shifts, or having little notice of changes in scheduling. There are, however, ways of using algorithmic scheduling such that the practice includes workers' preferences for availability and gives workers adequate notice of changes to the schedule; these practices have been shown to improve worker productivity and sales.[69] While scheduling software is not in wide use today, based on interviews for this project, interest appears high in applying just-in-time scheduling in the warehouse.

The conditions of work in warehouses may be heading toward more rigid forms of monitoring and management. If warehouse workers had little autonomy under existing forms of management, a new regime of machine surveillance could make working conditions more unforgiving. With little transparency into the algorithms being used, employees may question whether the same standards are being applied across the workforce.

4. In the short to medium term, new technologies likely will not cause widespread job loss.

With continued growth in demand, aggregate employment levels in the warehousing industry likely will continue to rise over the next five to 10 years. That said, job growth may be tempered by the increased use of labor-saving technologies in e-commerce warehouses in particular. Many workers will see their working conditions shift as technologies are adopted for particular tasks. Over the long term, in the absence of major shifts in the economy or context of firms' technological adoption strategies, the increasing use of technology points to a labor reduction.

Some warehouse technologies that are labor-replacing include:

- Automated storage and retrieval systems (ASRS), which are highly efficient but also costly, decreasing the size of the potential market that might adopt this technology; the main impact on workers of ASRS uptake is to reduce employment, since by design it replaces the need for order pickers.

- Autobaggers and autoboxers that automatically package outbound orders; in a high-volume e-commerce operation, managers report the elimination of 20 to 30 packing workers through the application of automation to the packing process.
- Sensors or RFID tags applied to goods, which allow warehouse operators to track the location and quantity of inventory through a centralized dashboard, rather than relying on workers to count and track products.
- Similarly, drones that automatically perform inventory counts are the subject of widespread interest, but are active in very few warehouse environments at this time because of cost.[70]

Section 4 of this report detailed a set of push factors and constraints that form the current context for technological advances in warehousing. The push factors include tight labor conditions, rising real estate costs, and increased speed requirements; whereas the constraints are the variability in the industry, outsourcing dynamics, inertia, and the state of technology. Significant shifts in any of these dynamics could shorten the timeline for labor replacement and thus job loss. For example, unloading containers requires significant manual labor, and major industrial equipment companies such as Honeywell have developed massive robotic unloading machines that substantially reduce the offloading time and all but eliminate workers from the process. But these technologies still are limited by variable conditions: all boxes in a container must be uniform in size and fall within particular weight parameters, circumstances that remain rare in warehouses today. Without standardization of goods within containers, or a leap forward in the technology's ability to deal with variability, these advances likely will be slow to proliferate.

Finally, the flip side of technologies applied to the above processes is that some products and activities are less amenable to technological applications. The most prominent category is "nonconveyables," or goods that are too big, heavy, awkward, or varied to move using a conveyor system. Examples include hot tubs and canoes, but also perishable foods like meat and some produce. Nonconveyables often are routed into separate inbound and outbound handling processes because they require manual handling, and some companies outsource the distribution of nonconveyables completely to shed the inefficient operation. Nonconveyable goods handling presumably will remain a largely manual process for the foreseeable future, not subject to reductions in employment opportunities.

> **"Newly available products, such as "wearable" warehouse technologies, follow-me carts, and increasingly sophisticated labor management software, allow more granular tracking of workers' movements, including walk speed, routes, bottlenecks, and break time.**

5. Technology is likely to have uneven impacts across demographic groups and occupations.

Technological change, as was noted earlier, is often uneven in its effects across the labor force. Some technologies will disproportionately impact the employability of older workers, such as engineered labor standards that penalize workers for not reaching exacting productivity targets. Furthermore, new technologies could be especially detrimental to the earnings of certain groups of workers, especially in warehouses that use merit pay or bonuses for productivity as core elements of employee pay. Older workers also may find new workplace technologies more intimidating than their younger counterparts, given that younger workers are more likely to have encountered computerized systems at work or at school.

Women Warehouse Workers

Women are more likely to work in e-commerce fulfillment centers than in traditional warehouses, which expands the employment prospects available to women workers in a traditionally male-dominated industry. Table 2.3 showed that across all occupations, 44% of workers in the warehousing segment of the e-commerce sector are women, versus 28% of workers in traditional warehousing. Yet, as Section 2 showed, there is a wage penalty for some e-commerce occupations relative to traditional warehouses, which suggests that a shift of work hours to e-commerce in effect could reduce overall wages. For example, nearly half (48%) of e-commerce stock clerks and order fillers are women, yet stock clerks in e-commerce earn $2.32 less per hour than their counterparts in the warehousing industry. Further research is required to determine whether the observed wage differentials reflect a gender bias in pay or whether the pay structure in e-commerce facilities is lower regardless of workers' gender.

In addition, e-commerce order volatility translates into greater scheduling instability, and perhaps extended periods in which nominally full-time workers are employed part time. Conversely, mandatory overtime, particularly on short notice, can be especially difficult for workers with child care responsibilities, which suggests that women would be disproportionately affected by scheduling uncertainty. In short, while e-commerce may offer new employment opportunities to women, some of the benefits of employment could be counteracted by the instabilities that are endemic to warehousing activities.

Summary Occupational Analysis

The following analysis focuses on the effects of technology on the five largest front-line occupations in warehousing, which account for nearly two-thirds of all workers in the industry. The variation in the demographic makeup of these occupations portends uneven exposure to

technological change. Bear in mind that for the industry as a whole, Latinx and Black workers are overrepresented compared with the total U.S. workforce: both groups are employed in warehousing at roughly twice the rate of all of other industries. Male workers also are disproportionately represented: while 47% of the U.S. workforce is male, 72% of workers in warehousing and 56% in e-commerce are male.

Laborers and Freight, Stock, and Material Movers, Hand
Stock Clerks and Order Fillers
Packers and Packagers, Hand

The three occupational categories above are used somewhat interchangeably for picking, packing, sorting, and shipping jobs in a warehouse. Warehouse workers who are involved in order picking might be counted in any of these occupations, and thus this report considers the effects of technology on order picking across the three categories. Together, these three occupations account for 43% of all warehousing industry jobs and 67% of front-line warehousing jobs.

Recent employment growth suggests that even though technology will be used increasingly in the order-picking process, significant net job losses in the industry are unlikely to occur over the next five to 10 years. This forecast relies, however, on the continued growth of e-commerce and the robust health of the U.S. economy. Further, depending on the widespread adoption of certain technologies, productivity improvements might slow employment growth. These three warehouse occupations may have the highest exposure to technological change because of their prevalence in e-commerce warehouses, coupled with warehouse operators' stated goal to apply technologies to the each-picking process. Conversely, order assembly still will require human pickers for some time to come. Although there is considerable excitement in the industry over the potential of robotic grippers, it likely will be many years before a dexterous robotic picking arm with near-perfect picking accuracy will be available at a sufficiently low price point for it to be widely adopted.

> **"E-commerce order volatility translates into greater scheduling instability, and perhaps extended periods in which nominally full-time workers are employed part time.**

The demographics of workers in these occupations differ somewhat between the warehousing and e-commerce industries, so the workers most likely to be affected by technological change are worth specifying in detail. As Table 6.1. shows, workers in order-picking occupations in e-commerce are more likely than their counterparts in warehousing to be female, White and young. While warehouse workers are more likely to be male in both industries, female workers make up 45% of this workforce in e-commerce, compared with 34% in warehousing. White workers constitute the largest race/ethnic category in

e-commerce (45%), while Latinx workers are the largest single race/ethnic group in warehousing (36%). Black workers account for roughly one-quarter of the workforce in both industries. Finally, young workers, particularly those ages 18–24, are the largest age group in both industries.

TABLE 6.1

Demographic Characteristics of Workers in Order-Picking Occupations*

	Percent of Workers in Picking Occupations in Warehousing Industry**	Percent of Workers in Picking Occupations in E-commerce Industry***
Gender		
Male	66%	55%
Female	34%	45%
Race/Ethnicity		
Black, Non-Latinx	26%	26%
Hispanic or Latinx	36%	19%
Asian, Non-Latinx	4%	6%
White, Non-Latinx	32%	45%
Other, Non-Latinx	2%	4%
Age		
18–24	29%	37%
25–34	28%	26%
35–44	17%	16%
45–54	15%	12%
55–64	8%	7%

Source: American Community Survey 2013–2017

*Order-picking occupations are Laborers and Freight, Stock, and Material Movers, Hand; Packers and Packagers, Hand; and Stock Clerks and Order Fillers.

**NAICS 493

***NAICS 45411

Depending on the technology implemented, workers in these three occupations may see their travel distances within warehouses decrease, since walking is a high-priority activity for the application of new technologies. This might improve the quality of these jobs somewhat by reducing the need for walking and cart pushing, though, as noted in the previous section, employees likely will experience work intensification alongside automation. Human dexterity will be required for the process of grasping of products and placing goods in either boxes or in totes to be moved to the next task station, so workers in order-picking occupations will continue to perform these tasks and likely see their productivity expectations rise. For workers packing orders into boxes and bags for shipping, autoboxing and autobagging technologies could reduce employment opportunities.

Industrial Truck and Tractor Operators (Forklift Drivers)

The most likely technology that would affect this occupational category is the automated guided vehicle (AGV), a well-developed but still costly solution. Forklift drivers require skill and certification, and often command slightly higher wages than other warehouse workers—in fact, forklift drivers are the highest-paid of front-line warehouse workers, and overwhelmingly male (Table 6.2.). White and Latinx forklift drivers make up the largest race/ethnic groups in both warehousing and e-commerce, and Black workers account for roughly one-quarter of forklift drivers. Compared with other warehouse occupations, forklift drivers are more likely to be older.

Simple horizontal pallet moves are easily handled by AGVs, though vertical moves—lifting and placing a pallet on racking—require precision so that goods are not damaged. According to the industry insiders interviewed for this report, the current high cost of AGVs limits the feasibility of implementation in many warehouses. What may change is that companies will begin to capture more data from forklifts and drivers, with at least three possible applications: to understand equipment utilization rates, to inform and improve the next round of AGV development, and to increase the productivity of drivers.

TABLE 6.2

Demographic Characteristics of Industrial Truck and Tractor Operators (Forklift Drivers)

	Percent of Forklift Drivers in Warehousing Industry*	Percent of Forklift Drivers in E-commerce Industry**
Gender		
Male	93%	82%
Female	7%	18%
Race/Ethnicity		
Black, Non-Latinx	26%	25%
Hispanic or Latinx	34%	36%
Asian, Non-Latinx	2%	–
White, Non-Latinx	36%	35%
Other, Non-Latinx	2%	–
Age		
18–24	18%	40%
25–34	31%	17%
35–44	24%	19%
45–54	17%	18%
55–64	10%	6%

Source: American Community Survey 2013–2017

*NAICS 493 **NAICS 45411

Shipping, Receiving, and Traffic Clerks

With the advent of AI-assisted receiving processes, this occupation could undergo significant change (Table 6.3.). Freight transportation is becoming increasingly digitized in light of demands for the real-time visibility of truck shipments, though here, too, adoption is uneven across the industry. As this digital capability improves, changes at the nexus of trucking and warehousing will follow, especially in the process of scheduling truck deliveries. WMS software increasingly will integrate AI into planning functions, and these advancements will infringe on what has been the purview of workers in this occupation, possibly leading to a reduction in staffing levels. Major change will depend on the extensive uptake of these technologies, which will be led by first movers who use the most advanced WMS systems and implement digital tracking across the freight-transportation function. Males constitute the majority of workers in this occupation in both industries, and thus have a higher exposure to job change or staffing reductions. White workers make up nearly half (47%) of shipping, receiving, and traffic clerks in e-commerce, and Latinx and White workers each compose 37% of this occupation in warehousing.

TABLE 6.3

Demographic Characteristics of Shipping, Receiving, and Traffic Clerks

	Percent of Shipping, Receiving, and Traffic Clerks in Warehousing Industry*	Percent of Shipping, Receiving, and Traffic Clerks in E-commerce Industry**
Gender		
Male	69%	57%
Female	31%	43%
Race/Ethnicity		
Black, Non-Latinx	20%	26%
Hispanic or Latinx	37%	19%
Asian, Non-Latinx	4%	5%
White, Non-Latinx	37%	47%
Other, Non-Latinx	3%	4%
Age		
18–24	27%	38%
25–34	30%	23%
35–44	18%	15%
45–54	16%	15%
55–64	8%	9%

Source: American Community Survey 2013–2017

*NAICS 493 **NAICS 45411

Conversely, and with effects across all occupations, warehouse facilities that do not implement new technologies likely will experiment instead with evolving labor strategies to manage demand volatility and risk, as well as to improve efficiency. This could include the increased use of mandatory or voluntary overtime, temporary staffing arrangements, additional shifts, and incentives based on productivity.

SECTION SEVEN:
Conclusion

Technology adoption is not a risk-free undertaking, and there are a number of features of the warehousing industry that inhibit innovation. Lead firms are likely to be in the most advantageous position when it comes to experimenting with new technologies, and e-commerce is driving this trend. Large retailers like Amazon, for example, may be able to leverage both their sizeable order volumes and strong financial positions to secure first-mover advantages through early adoption of new technologies. Furthermore, because they manage their supply chains, and therefore set contracting arrangements, lead firms are not subject to short contract terms and other provisions that elevate the risks incurred when making substantial investments in new technologies. With this said, however, impediments still remain. For the foreseeable future, product variability will continue to present challenges to automation, as do fluctuating order volumes and the overall volatility of consumer demand. Large and small firms alike can face these constraints, and though lead firms certainly have incentives to make investments in logistics infrastructure, such constraints nevertheless serve to slow experimentation.

Most 3PLs face even greater challenges. Chief among these is the cost-based competition that is a defining characteristic of the warehouse industry. Cost-based competition holds down the margins of warehouse operators, and when combined with short subcontract terms, it renders technological experimentation a risky endeavor. Even under the best of circumstances, technological experimentation exposes warehouse operators to financial risks, and the need to secure an adequate return on investment plays a decisive role in technology-spending decisions (especially given that macroeconomic changes can sharply shift patterns of consumer spending). Short contract terms exacerbate these risks, and without the assurances provided by strategic, long-term partnerships with lead firms, a cautious approach to experimentation will prevail. Moreover, because securing upfront investment may prove challenging, especially given the low margins and the general absence of long-term contracts, most operators have taken a cautious approach, which has moderated the scope and pace of change.

For these reasons, widespread full automation of warehouse occupations is little more than a remote possibility over the near to medium term, despite the rapid technological advances that are being made. To the extent that technological adoption occurs within this timeframe,

experimentation is more likely to occur among lead firms than in the 3PL market, though the possibility of diffusion from early-adopting lead firms to other operators remains.

Partial automation and labor augmentation, on the other hand—where a particular subset of occupational tasks or activities lends itself to a viable technological application—are far more realistic objectives. In the majority of cases, labor augmentation likely will be the most common path of short- and medium-term technological change, and has the potential to alter the content and quality of workers' jobs significantly. It is conceivable that workers will stand to benefit from ergonomic improvements as new technologies replace walking, lifting, repetitive motion, and other physically demanding activities. Where such improvements in health and safety are made, it is imperative that they are not compromised by work intensification. Advances in warehouse ergonomics, including reductions in strenuous, manual activities, could be accompanied by increasing demands on the pace of work and sharply rising workloads. Work intensification could lead to the introduction of new hazards on the job, arising from the presence of new technologies in the workplace or from worker fatigue.

Another possible outcome resulting from the implementation of new technologies is de-skilling. From the perspective of the warehouse operator, de-skilling can enable reductions in worker training time and turnover costs. Simplifying work tasks allows employers to expand the potential labor pool and increase the use of temporary workers. The impacts on workers, however, can be deleterious, leading to further wage stagnation and erosion of job stability.

Over the long run, especially as the technologies being implemented today are used to collect data that will inform the development of next-generation robotics, automation will become more widespread. But the negative effects on employment levels are not predetermined. In one prominent example of automation without worker displacement, Boxed outfitted its distribution center with leading-edge automated processes. Instead of laying workers off, the company trained them to fill new roles around the equipment. This was possible, however, because of the rapid growth of the business: automation allowed Boxed to handle increasing volumes without more workers, and this enabled the return on technology investments. However, even in this case, should growth slow or reverse, this strategy might not be sustainable.[71]

The findings from this research raise a number of questions for policy makers, worker organizations, and industry leaders.

Variation in adoption is likely to be an ongoing feature of technological change in the warehousing industry. As a result, effects on facilities and workforces will differ, requiring careful attention to avoid disproportionate impacts on workers who have higher exposure to job change and eventual job loss, especially workers of color (who are disproportionately represented in front-line warehousing occupations) and women (who are more likely to work in e-commerce).

How can policy makers, equipped with forward-looking information, help to plan and prepare for changes in job quality and the potential unequal distribution of the costs and benefits of technology adoption? What new policies might promote job security to help support workers and their families as technologies change the nature of warehouse work?

A number of the new technologies covered in this report introduce workplace dynamics that have few precedents. The growing use of technology to monitor and manage workers raises ethical issues regarding data privacy, as well as concerns about workplace morale, as electronically mediated forms of supervision threaten to constrain workers' autonomy and introduce new rigidities into the workplace. These, in turn, could lead to increased employee turnover. Algorithmic transparency, data privacy, and worker surveillance are nascent issues that require serious attention by industry leaders, worker organizations, and policy makers. *How might including workers in the process of technology implementation improve employment and operational outcomes? What safeguards might be necessary in order to ensure workers' data are protected?*

Little is known about the range of effects new technologies will have on health and safety over the long run, and it is possible that technologies will have both positive and negative implications for jobs and workers. Workers might feel increased stress and anxiety as a result of electronic monitoring, ergonomic benefits might be coupled with new health and safety risks, and increasing productivity requirements might lead to exhaustion and overwork, possibly hampering employers' efforts to attract and retain workers. *What measures can be put in place to track the physical and psychological impacts of technologies on workers to mitigate any negative effects on workers' health and safety? How might developers' research and design efforts better incorporate an assessment of the full effects of new technologies on workers' well-being?*

Finally, proactive measures are necessary to support workers who are displaced by new technologies to transition to alternative employment opportunities. It is conceivable that, over the long term, the warehousing industry will offer fewer employment opportunities. Policy makers and employers can begin planning today for programs that will prepare workers for nonroutine and newly created jobs in warehousing or to support them as they move to other industries. *What efforts can ensure a safety net for labor market dislocations caused by the introduction of new technologies in order to ease the burden on displaced workers? How can policy makers involve employers in systematically identifying within-industry job opportunities for displaced workers, including on-the-job training?*

Warehouse operators stand to gain substantial efficiencies through technological advances. How these gains will be distributed, especially given the findings of this report, is a pressing question for policy makers, worker organizations, and industry leaders alike. Warehouse operators have latitude in determining how new technologies will be implemented. It is imperative that productivity gains be shared, that workers be involved in identifying which efficiencies should be prioritized and what hazards are being introduced, and that experimentation unfolds with regard for more than just productivity increases. Absent this, the process of technological change in warehousing will resemble a win-lose proposition, where the short-term benefits are captured by the industry and the long-run costs are borne by workers.

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