THE NEW YORKER

WELCOMING OUR NEW ROBOT OVERLORDS

Once, robots assisted human workers. Now it's the other way around.

By Sheelah Kolhatkar

When David Stinson finished high school, in Grand Rapids, Michigan, in 1977, the first thing he did was get a job building houses. After a few years, though, the business slowed. Stinson was then twenty-four, with two children to support. He needed something stable. As he explained over lunch recently, that meant finding a job at one of the two companies in the area that offered secure, blue-collar work. "Either I'll be working at General Motors or I'll be working at Steelcase by the end of the year," he vowed in 1984. A few months later, he got a job at Steelcase, the world's largest manufacturer of office furniture, and he's been working at its Grand Rapids metal plant ever since.

Stinson is now fifty-eight. He has a full, reddish face, a thick head of silver hair, and a majestic midsection. His navy polo shirt displays his job title—"Zone Leader"—and, like everyone else in the plant, he always has a pair of protective earplugs on a neon string draped around his neck. His glasses have plastic shields on the sides that give him the air of a cranky scientist.

"I don't regret coming here," Stinson said. We were sitting in the plant's

cafeteria, and Stinson was unwrapping an Italian sub, supplied by a deli that every Thursday offers plant workers sandwiches for four dollars instead of eight. “There’s been times I’ve thought about leaving, but it’s just getting to be a much more comfortable atmosphere around here. The technology is really helping that kind of thing, too. Instead of taking responsibility away from you, it’s a big aid. It’s definitely the wave of the future here.”

William Sandee, Jr., a sixty-four-year-old worker on the paint line, sat down next to Stinson with a carton of fries and a cup of ketchup, and tossed his safety goggles on the table. “We try to have some fun with it,” he said in a low near-growl. “It can get intense.”

Sandee, who has neatly combed gray hair and an alert, owlish face, began working at Steelcase in 1972, after waiting in line with six hundred people just to put in an application. “They made it very lucrative to be a Steelcase employee, back in the day,” Sandee said. Plant managers were known to drive fancy cars and have second homes on the lake; the company paid the college tuition for employees’ children, who often spent summers working at the local plants; and there were company picnics and a bowling tournament, which once had fifteen hundred players. (The tournament is still held, now with around three hundred participants.)

In the nineties, Steelcase employed more than ten thousand workers in the United States and operated seven factories around Grand Rapids, making chairs, filing cabinets, desks, and tables, and the screws, bolts, and casters that went into them. Packed shoulder to shoulder, workers polished and painted wood and assembled steel parts by hand. Today, there are only two Steelcase plants in Michigan—the metal factory, which makes desks and filing cabinets, and a nearby “wood plant,” which produces wood furniture. In total, they employ fewer than two thousand workers. The company’s only other U.S. plant, in Athens, Alabama, employs a thousand full-time workers.

The history of Steelcase, in many ways, is the history of manufacturing in America. The company was founded in 1912 with one product, a fireproof metal wastebasket. As the economy boomed in the following decades, America's burgeoning corporations needed to furnish their offices with desks and shelving and cubicle walls. "If you were a high-school kid growing up in Grand Rapids in the eighties and you didn't want to go to college, and you got a job at a Steelcase factory, you were set," Rob Kirkbride, who covered Steelcase for almost two decades at the Grand Rapids *Press* and industry publications, told me. "It was like winning the lottery."

Then the dot-com bubble burst and countless startups found themselves auctioning off their office furniture. By 2001, Steelcase had lost a third of its sales and started closing plants throughout western Michigan. Its manufacturing was moved to Mexico, China, and eventually India. In 2011, the company announced a new series of closings and layoffs, shutting another plant near Grand Rapids, one in Texas, and one in Ontario, Canada. Almost all the company's chair manufacturing was relocated to Mexico.

VIDEO FROM THE NEW YORKER

Surfing on Kelly Slater's Machine-Made Wave

These days, as U.S. companies report record profits and demand millions of sleek new workspaces, Steelcase is again on the upswing. Its corporate headquarters, housed in a refurbished factory, is a laboratory of workplace trends, with open floor plans and glass-sheathed work pods where people recline with their laptops or hover at standing desks. In the two Michigan plants that remain open, employees create metal components for furniture sets and conference tables in dozens of shades of wood veneer.

As technology is making the work faster, more efficient, and more environmentally sound, the products are being created with far fewer workers. "Companies are obviously not sending out press releases saying, 'We're not hiring more people,' but that's what I hear on the street," Kirkbride said. There are automated assembly lines, and robotic arms lifting tabletops that were once hauled by men. Stinson took me across a dense wall of machinery and past a giant contraption that makes cardboard boxes so that the plant doesn't have to order them. "You can just punch it into the

touch screen there and go, I need 86-17, *boom-boom-boom,* I need fourteen of 'em. Hit the button, and it cuts it for you," he said. "That kind of stuff is really cool. So it isn't so much that we're eliminating jobs, we're eliminating the waste."

As a zone leader, Stinson is responsible for about fifteen employees on a section of the production line that makes parts for Steelcase's Ology series —height-adjustable tables built for the standing-desk craze. Until last year, the plant workers had to consult a long list of steps, taking pains to remove the correct parts out of a cart filled with variously sized bolts and screws and pins and to insert each one in the correct hole and in the correct order. Now computerized workstations, called "vision tables," dictate, step by step, how workers are to assemble a piece of furniture. The process is virtually mistake-proof: the system won't let the workers proceed if a step isn't completed correctly. We stood behind a young woman wearing a polo shirt and Lycra shorts, with a long blond ponytail. When a step was completed, a light turned on above the next required part, accompanied by a *beep-beep-whoosh* sound. A scanner overhead tracked everything as it was happening, beaming the data it collected to unseen engineers with iPads. Employees who follow a strict automated protocol—some call them "meat robots"—need little training. Even the drill was attached to a computer-assisted arm; the worker just had to move it to the right position and let the machine do its magic. A decade ago, industrial robots assisted workers in their tasks. Now workers —those who remain—assist the robots in theirs.

For decades, the conventional view among economists was that technological advances create as many opportunities for workers as they take away. In the past several years, however, research has begun to suggest otherwise. "It's not that we're running out of work or jobs per se," David Autor, an M.I.T. economist who studies the impact of automation on employment, said. "But a subset of people with low skill levels may not be

able to earn a reasonable standard of living based on their labor. We see that already." As automation depresses wages, jobs in factories become both less abundant and less appealing.

This process, Autor and other economists argue, can also exacerbate inequality. The labor market is built around the idea of labor scarcity: each person has a bundle of labor—his or her own capacity to work—that employers need and that she can sell in the job market through employment during the course of a career of thirty years or so. That model is eroding. "It doesn't mean there's no money around, but it's just accruing to the owners of capital, to the owners of ideas," Autor says. "And capital is less equitably distributed than labor. Everyone is born with some labor, but not everyone is born with capital."

In the Steelcase metal factory, automation has led the company to seek out more highly educated managers, who are now expected to have a college degree, not just a high-school diploma. The company, following the "lean manufacturing" model pioneered by Toyota, hires young engineers to scan factory data for additional "efficiencies," which can translate into further automation. For people who have technical degrees and can manage automated systems, and for owners of companies that are in the process of automating, the potential for increased wealth is significant. But for less skilled workers it's a different story. In a paper from earlier this year, the economists Daron Acemoglu, of M.I.T., and Pascual Restrepo, of Boston University, studied local job markets in the United States between 1990 and 2007, and they found that the concentration of industrial robots in an area was directly related to a decline in jobs and in pay. Technology can compound the effects of globalization. By one measure, the average manufacturing worker in the United States earned nine per cent less in 2015 than the average worker in 1973, while the economy over all grew by two hundred per cent. At Steelcase, Stinson acknowledged, workers were earning

around the same dollar salary that they had in 1987.

Neither Stinson nor Sandee thought that automation posed a threat to their jobs, though. Sandee remembers when Frank Merlotti, a legendary figure at Steelcase who retired as president and C.E.O. in 1990, used to visit the plant and deliver rousing speeches to the workers. “Frank would look at you, and he would say this before he would even say much of anything,” Sandee recalled. “ ‘Listen,’ he says, ‘it’s you people, you people, all you people out here who make this thing work, who make it happen.’ ”

Sandee speaks fervently about the dignity of manual labor. He told me about a trip he had taken with his grandkids to New York City, where they had visited the Empire State Building. “You’ve probably seen that picture of those guys, where they’re sitting way up there on all that steel, up there, they’re eating their lunch together,” Sandee said. “And they got some rivets and stuff there. But the rivets, in my opinion, are the people.” He seemed to be describing a famous black-and-white photograph titled “Lunch Atop a Skyscraper.” “That was one of the nicest things I saw there, of all of New York City, it was those old-timers. Building that building. How did they do it, you know? It’s amazing.”

In Sandee’s opinion, there was something irreplaceable about the combination of sentient judgment and human hands. Think of all the things that robots couldn’t do: get their hands into things; unpack a box; close a twist-tie. Even in an automated future, he thought, you’d need people to apply the wisdom gained through age and experience. “You’re still gonna have to have the people here,” he said. “Somebody’s still gotta man that machine that’s supposed to be able to do everything. And tell us when that machine doesn’t want to work the way it’s supposed to.”

The Humans to Robots Laboratory, at Brown University, is on the ground floor of a red brick building in the center of Providence, Rhode

Island. It has the feel of an oversized garage, filled with stained, lumpy sofas and scattered gadgets and toys, along with the odd takeout food carton. There, on a recent afternoon, a robot with bulky red arms set about pulling the petals from an artificial daisy. The robot, known around the lab as Winnie, held the flower in a pair of rubber-tipped pincers, then retracted its other arm, rotated it slightly, and pointed it down toward the daisy. It emitted an idling-motor sound, as though contemplating what to do next. Then the hand jerked down toward the flower, grabbed a petal, and flung it on the table. It retracted again, with a mechanical *reeeh-raaah!* noise. The movements evoked a prehistoric bird.

The lab was created by Stefanie Tellex, a computer-science professor who studies ways to create robots that can work coöperatively with humans. "Broadly, my research program is about making robots that can work with people on complex tasks," Tellex told me. "We're trying to make robots that can robustly perceive and manipulate the objects in their environment."

The word "manipulate" comes up often among roboticists. Even in highly automated factories, jobs that involve packing boxes or putting tiny parts together are done by people. The most agile robot, confronted with an object that it's never seen before, can pick it up only ninety per cent of the time, which isn't good enough for industrial purposes.

Solving this problem—teaching a machine to handle a random assortment of irregularly shaped objects—would have an immense impact; Tellex envisages machines that change diapers and prepare dinner. In her class Topics in Collaborative Robotics, one student proposed to teach a robot to make a salad. "It's very difficult, and probably not very cost efficient, for a robot to make a salad," Tellex's teaching assistant, Josh Roy, said. "We joked that we could make a thirty-thousand-dollar salad with a robot." Part of the challenge, whatever the task, is devising an "end effector"—the handlike tool

at the end of the robot's arm—that can grip a variety of shapes and sizes and textures with different levels of pressure. The more complex part, and the part that preoccupies Tellex, involves teaching the robot to perceive the different objects so that it understands what it's supposed to do.

Winnie was programmed by one of Tellex's students, Rebecca Pankow, a first-year Ph.D. candidate with bright brown eyes and dimples. "It's not very refined," Pankow said, as Winnie continued pulling petals. "This is more of a proof of concept." She went on, "I chose this project because I thought it was an interesting computer-vision problem. It's applicable to other things that I work on outside this class. And I just thought it was very cute."

An industrial robot will pick up the same object, in the same location, over and over. The challenge, and the multibillion-dollar business opportunity, was to teach a robot to function in an environment that was constantly changing. This was Winnie's assignment. "There's a saying in robotics: Anything a human being can do after age five is very easy for a robot," one of Tellex's students had said to me earlier. "Learn to play chess, no problem. Learn to walk, no way."

John Oberlin, another Ph.D. student, who wore a long brown ponytail, safety goggles, and sandals with wool socks, bent his tall frame over a computer on a side table. The screen showed what Winnie was "seeing" through its hand-camera. "If I were going to try and pick up this tape over and over"—Oberlin picked up and dropped a roll of masking tape—"it only exists in one way, on the table," he told me. "So I can just memorize what it looks like in one way, and then all I have to do is search this space, basically. But these petals on this flower have more than one way to fall. Sometimes they can be rotated a little bit, sometimes they can droop, sometimes they can curve, so these petals are deformable. And that makes them inherently harder to localize."

Pankow had retrofitted an artificial flower with little magnets on its petals, so that they could be reattached and reused. “The camera is currently taking a picture of the table,” she said. “And then you put the flower there, and it will take the picture again. And it will say, ‘Oh, look at the difference between the two—a flower has appeared.’ ”

Winnie’s arm moved in, clamped its pincers around a petal, plucked it off, and then threw it onto the table. It made the *reeeh-raaah!* noise and then went back to idling. The cycle continued until there was only one petal left. It was sticking out at an awkward angle, and Winnie’s arm hovered for a long time above it. Pankow and Oberlin watched nervously.

Winnie moved in, its arm quivering slightly, and positioned its arm to the outside of the flower in a way that looked unlikely to succeed. The grippers opened, trying but failing to close around the petal. Then the arm pulled up again. *Reeeh-raaah!*

Oberlin adjusted the flower. “I bet it comes down a little bit . . .” he said. This time, Winnie managed to peel off the final petal.

Pankow and Oberlin spoke about the adjustments that would have to be made for the technology to be usable in the real world. “You can imagine this ability to classify or examine plants or other structures in terms of their parts, in order to compose or localize each one of those petals—that has applications in actual industry,” Oberlin said. “You can imagine applying that modelling technique to real plants.”

“Blueberries,” Tellex said quietly, leaning against the window. “That’s my goal. People aren’t going to pay us to take petals off of daisies. But they will pay us to pick blueberries.” She looked down at the table and the bare daisy stem. “Did it just pick all of these? In order? This is awesome. This is not something I’ve ever seen a robot do. And that’s cool. And now we’ve figured

some things out, as a result of doing this."

Harvesting fruit and other produce, which involves hours under the hot sun, is the kind of job that Americans are increasingly reluctant to do and that often goes to low-paid immigrant labor. Yet the implications extend beyond agriculture. A robot that could efficiently pick blueberries could probably do a lot of things that are currently the exclusive province of human beings. Potentially, it could advance on a frontier challenge of industrial robotics—not only picking a wallet out of a bin but riffling through it and pulling out a credit card.

"I usually like to ask the question: How can this help make society better?" Tellex said. "What is something that people do now that robots might do?"

Corporate executives want to know the answer to that question, but they seldom ask it publicly. Automation is a topic that gets treated with enormous diplomacy, both in Europe and in the United States. The Dutch supermarket chain Ahold Delhaize, which owns the Stop & Shop and Peapod grocery-store brands in the U.S., hopes to have all its retail outlets cleaned by robots within five years. Although the company was not eager to publicize the details of the venture, the images that spring to mind are part Isaac Asimov and part Dr. Seuss—doors closing with a thud and the aisles bursting to life, with metallic objects scampering across the floor, brightly colored squeegees and sponges dropping from the ceiling, followed by an explosion of soapsuds and baby carrots. But the goal wasn't to replace human workers, a company spokesperson insisted. With store-cleaning robots, "our associates in our stores will have more time for customers."

Such initiatives aren't limited to private businesses; neither are the sensitivities. In southern Denmark, the regional government hired a chief robotics officer, Poul Martin Møller, to help integrate more robots into the public sector, largely as a money-saving measure. He decided that the

Danish hospital system, which was under pressure to reduce costs, could benefit from robotic orderlies. There were few medical-oriented robots on the market, though, so Møller and his team took small, mobile robots with movable arms, designed for use in warehouses, and refashioned them, so that they could carry supplies to doctors and nurses. The machines worked well, scuttling through surgery wings and psych wards like helpful crabs, never complaining or taking cigarette breaks. But Møller wasn't prepared for the reaction of the hospital staff, who recognized their mechanical colleagues as potential replacements, and tried to sabotage them. Fecal matter and urine were left in charging stations.

Since then, Møller has evangelized about "change management," and the need to handle people carefully as new technology is introduced. "As a taxpayer, here we pay thirty-three, thirty-four dollars an hour for unskilled work, like orderlies," he told me. "Robots cost, at most, around ninety-five cents an hour. If you do the math, you can have thirty-five robots for one human. So you might as well face reality and face facts. That means you have a bunch of orderlies who need jobs." By way of redress, he proposes using the robot-derived savings, at least initially, to retrain the displaced humans for more sophisticated jobs that the robots can't (yet) do.

In the United States, where automation in the workplace is no less politically fraught, corporate executives are reluctant to be quoted on the subject; when they are, their usual line is that robots aren't replacing humans but simply helping to make their jobs less taxing. This is not entirely a misrepresentation. When I asked Dave Stinson and his colleagues at Steelcase about how automation had affected the assembly line, they said, for the most part, that it had made things easier. The factory was cleaner, less noisy, more productive. When something went wrong with the assembly, they could diagnose the problem swiftly, by consulting the data. Most workers welcomed being rotated through different positions, rather than

doing the same thing for years at a time.

The work placed less stress on their bodies, too. At one time, twenty-five hundred steel tabletops came off the assembly line each day, requiring two men to sweat and strain to get each one into the right place; now a robotic arm with grippers moved the tops. Workers—the ones who had survived the economic downturns, offshoring, and technological changes—had an easier time than ever before. In the old days, Stinson said, "It was, How much longer am I going to be able to do this? That's kind of a question that you would always ask—how much longer can I hold up doing this, physically just holding up? Ergonomically, the difference today is huge. Huge." Now he could work longer without burning out, and the work was easier. Who could complain about that?

Automation has also increased the amount of manufacturing in the United States, by making it more efficient. The most immediate way that it makes manufacturing more efficient, of course, is by requiring fewer workers. Still, when manufacturing that has been sent overseas comes back, it brings some jobs back, too, even if they are not the same complement of jobs, and not in their old numbers. Last year, for the first time in decades, the number of Americans employed in manufacturing increased—more jobs returned or were created than left—and automation-enabled "reshoring" is a big reason for that.

In a hundred-and-twenty-five-thousand-square-foot factory in the town of Hatfield, Pennsylvania, forty-five minutes north of Philadelphia, dozens of giant, automated industrial presses loom over a cement landscape. They belong to the Rodon Group, one of the largest family-owned injection-molding companies in the country. Founded in 1956, the company makes millions of high-end plastic parts each year: containers for cosmetics, caps, pushpin heads, bottle tops.

One of Rodon's subsidiaries was a "construction toy" company—comparable to Lego and Fischertechnik—called K'Nex. The K'Nex line had been invented by the son of the Rodon Group's founder, and, in the late nineteen-nineties and early two-thousands, it was run by a former Hasbro executive. Hasbro, like most of the American toy industry, had moved its production to China, and the executive decided to do the same thing with K'Nex. There were trade-offs with outsourcing: quality control was less reliable, and it was harder to respond nimbly to changing customer demands in the trend-driven toy business. But the savings were dramatic; on average, it cost less than half as much to make a product in China as it did in the United States.

Michael Araten, the current C.E.O. of K'Nex Brands and the grandson-in-law of Rodon's founder, told me that business had been relatively stable until the financial crisis arrived, and sales plunged. Rodon laid off around forty people, about a third of its workforce. Araten said that when business picked up the discussion quickly turned to how the company could rehire those people. One obvious solution presented itself: K'Nex could bring its manufacturing back to the United States so long as it could remain price-competitive with the China-sourced toy companies. K'Nex managers concluded that reshoring was feasible, but they would have to automate as much of the process as possible.

On a recent visit, the plant's manufacturing floor was filled with the sound of molding presses clamping down with as much as four hundred tons of pressure. No people were visible. Most of the presses work twenty-four hours a day, drawing plastic resin into a hopper, heating it to six hundred degrees Fahrenheit, and then blasting the liquid into molds, which are enormous blocks of stainless steel, precision-fabricated in an adjacent tool shop to create the shape of the desired part. (The molds used to be hand-fashioned by tool-and-die-makers, who were considered artisans; now a series of programmable robots do most of the job.) Automated arms lift the

parts up to cool, before depositing them in boxes. The completed parts are bright orange, purple, and red, and resemble dime-store candies. Once the boxes are full, human workers replace them, and wheel the full ones away to be shipped out to their customers.

A twenty-five-year-old "automation tech" named John Wilson had been hired to help integrate robotics into the plant as it moved toward increasing automation. Wilson is pale and thin, with glasses and a dark beard; he speaks in a low monotone, and gives the sense of someone who is more comfortable interacting with screens than with people. The child of two accountants, Wilson completed a mechanical-engineering degree at Philadelphia University in 2014, and said that he had sought out a manufacturing job where he could work directly with different types of automated machines. The Rodon Group had obliged. During Wilson's three years at the company, twenty-four new automated presses have been introduced. There was a time when a plant worker was dedicated to each press, shovelling in plastic polymers, pulling the cranks and pushing the buttons, and scooping out the finished products and loading them onto trucks. Now, Wilson explained, one operator manages between eight and ten presses, which are overseen by digital systems. As at Steelcase, the robots have reduced accidents. When I asked if there were any jobs in the plant that automated machines couldn't do, Wilson thought for a moment and said, "Cleaning up the floor after these machines, and machine-tending."

A robot picks apart a yellow daisy at Brown University's Humans to Robots lab.
Photograph by Grant Cornett for The New Yorker

By installing robots and controlling its payroll and other costs, the company has been able to make ninety per cent of its parts and products in the United States—a move that Araten likes to describe as "patriotic capitalism." Rodon and K'Nex use their made-in-the-U.S.A. credentials in their marketing.

President Obama visited the Hatfield plant in 2012; Hillary Clinton stopped by in 2016. “The choice of how you spend your money really matters,” Araten said. “If you buy stuff from an American farmer or manufacturer, you’re helping an American family.”

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Sitting in a company conference room that was lined with shelves displaying plastic toys and framed vintage production orders from the nineteen-fifties, Araten said, “I talk to C.E.O.s all the time who say, ‘It’s not my job to worry about the rest of the country.’ And I say, ‘Well, whose job is it? You’ve got to do what you can in the United States to keep the United States strong.’ ” He went on, “If you think there is a benefit to having a stable citizenry that has good-paying jobs, that can support a family, you need to be willing to make some trade-offs there. Our responsibility is, yes, to our shareholders but also to our employees, and to our community. We made a decision—we are willing to make less of a profit in order to keep jobs here.”

Araten acknowledged that, relative to sales, the Hatfield factory employed fewer people than it had done in the past. (Rodon’s revenue has grown by an average of fifteen per cent over each of the past five years, while its staffing has increased much more modestly.) But the jobs that they do have and will

have, he said, will be higher skilled and better paying. He argued that the government could encourage similar moves by other companies, through tax policy and major investments in education, while also preparing for the coming technological changes. Still, even Araten isn't immune from the call of high finance: last year, he and the rest of the family decided to sell K'Nex to a Chinese-French private-equity firm, Cathay Capital. It is unclear whether his new partners will be aligned, over the long term, with his people-before-profit philosophy.

"The winds are changing," Araten said. "I think part of the reason populism is rising around the world is that the gap is getting too big. Having so much inequality creates instability in a country. Maybe twenty years ago, we still had too many poor people, but they believed that they had a shot. I believe some of that is being sucked away."

Manufacturing jobs now account for less than ten per cent of the American workforce. As plants have closed, displaced employees have sought work in fast-food restaurants or in big-box retail stores, where the pay and the benefits are substantially less attractive. And, increasingly, even those jobs are fading away. Storefront retail is fast losing ground to the online marketplace. McDonald's is introducing "digital ordering kiosks" that are expected to replace human cashiers at fifty-five hundred restaurants by the end of 2018. Meanwhile, companies like Uber and Google are investing heavily in autonomous-driving technology, betting that such vehicles will reshape transportation. In August, 2016, Uber purchased Otto, a startup based in San Francisco that sells technology designed to automate long-haul trucking. There are nearly two million long-distance truck drivers in the United States, most of whom are male and lack a college degree; paying for them accounts for a third of the costs in the seven-hundred-billion-dollar trucking industry. Construction jobs, too, are threatened by automation; a New York-based firm has introduced a laser-guided system that can lay eight

hundred to twelve hundred bricks a day, more than twice as many as an average mason.

For low-skilled workers, warehouse jobs have seemed to be something of a bright spot. Even if fewer people are required to staff a Target or a Sam's Club outlet, the movement of products requires a network of warehouses to store and ship goods. Amazon—the world's largest online retailer—currently has more than ninety thousand employees at its U.S. distribution centers, and plans to hire tens of thousands more. Workers still do the "picking" in a warehouse, using their dexterous fingers and discerning brains to take soap and coffee and tubes of toothpaste and millions of other products off the shelves and put them into boxes to fulfill the online shopping orders that make up an increasing portion of consumers' buying patterns.

But the same factors that make warehouses a draw for labor have made them a tempting target for automation. In 2012, Amazon spent almost eight hundred million dollars to buy a robotics company called Kiva, which makes robots that can zoom around a factory floor and move tall stacks of shelves of up to seven hundred and fifty pounds in weight. A Deutsche Bank research report estimated that Amazon could save twenty-two million dollars a year by introducing the Kiva machines in a single warehouse; the savings company-wide could reach into the billions. With such a powerful incentive, Amazon is on a quest to acquire or develop systems that can replace human pickers. When, in June, it announced plans to buy the Whole Foods supermarket chain, speculation quickly spread that the company intended to automate the grocer's food-distribution centers as well as its stores.

Simply automating a legacy warehouse, however, is a halfway measure, as a visit to Symbotic makes clear. A privately held company based in an industrial park outside Boston, it sells fully automated warehouse systems to

large retail chains, and the new warehouses resemble the old ones about as much as a Tesla resembles a Model T. The company's twenty-thousand-square-foot test center is a giant cube of interlocking green, yellow, and white steel shelving, tracks, and cages that extend from the floor almost to the ceiling. There are no aisles for lifts to pass through, and no stations for human product pickers. There is no space inside the matrix for people at all.

Robotic arms unpack pallets of tomato sauce, salsa, toilet paper, and soda, and place them on a blue conveyor belt, where they are carried deep into the storage cage. A fleet of little green robots that look like race cars in a Pixar film come to life and zoom inside the cage on dedicated tracks, emitting high-pitched whirring sounds. They collect the cases of products and stash them on shelves until they are needed. Then an algorithm directs the little car-bots to go back in and bring the desired products out.

"This absolutely reinvents the warehouse," Chris Gahagan, Symbotic's C.E.O., said as he showed me around. He is a muscular fellow with dirty-blond hair pulled back in a ponytail, and looks as if he could have had an alternate career leading tourists on spelunking trips through Belize. "Now you can build an even smaller warehouse, or carry more SKUs, or serve more stores out of the same warehouse. It gives you huge flexibility."

Gahagan was recruited in 2015 by Symbotic's owner, Richard B. Cohen, the press-shy billionaire owner of the C&S grocery wholesaler. Cohen had wanted a system that would make his grocery warehouses more efficient; then he realized that he could make a business of selling it to other retailers. Symbotic says it now has more orders than it can swiftly fulfill. The automated system, Gahagan notes, produces more efficiencies than are obvious at first glance. Because it can store more products in a smaller space, companies could have more compact warehouses closer to their retail outlets, requiring less trucking. The robots don't need light to operate, so the

warehouse could use, Gahagan estimated, thirty-five per cent less energy than a conventional one, while reducing labor costs by eighty per cent. Many warehouse operators run their businesses based on labor hours, in order to minimize overtime pay, among other things. But an automated system could run twenty-four hours a day. A typical system costs around fifty million dollars to install, Gahagan said—not an insignificant investment. But, he maintained, it would pay for itself, on average, in four and a half years.

We walked past a "Safety Is Our First Priority" sign on the wall, an artifact from a time when there might have been frequent worker injuries in such a place, and clambered up a set of steel stairs. All around us, machines were moving, gracefully and tirelessly executing their tasks.

"You start to look at all the costs that you can avoid," he told me. "It's phenomenal. So, as soon as one company does this, it makes it more competitive." That instantly puts pressure on competitors to follow suit. "You can't just sit there being that inefficient," Gahagan went on. "Your assortment in your store is not as good, you're paying more for labor, more for trucking. If a new startup came along in retail, it would start with this." He gestured around at the cavernous, chilly space.

The most important human job at a Symbotic warehouse is that of the "system operator," which is akin to a job in flight operations, where you sit all day behind a bank of screens and make sure that everything's working right. A couple of human workers were needed—for now—to help unload and load the trucks as they came and went with the inventory, and four or so mechanics were kept on staff to service the bots when they needed it (because "shit happens"). In all, the average system requires eight or nine people per shift, a fraction of what a traditional warehouse requires.

Most jobs in warehouses are undesirable and hard to fill, Gahagan assured me. A typical worker might lift thousands of pounds of goods each day and

walk the equivalent of a marathon, five or six days a week. It could be freezing in the winter, and sweltering during the summer months. "Their turnover is huge," he said. With the robotic version, one higher-skilled person sits behind a console and types in commands, and is paid almost twice as much per hour as a manual laborer would be.

Gahagan was reluctant to talk about Symbotic's customers, who aren't keen to draw attention to their interest in nearly human-free warehouse systems. "There is some sensitivity, given our . . . political situation," he said. "It's just a reality of the times that we live in." But the *Wall Street Journal* has reported that Target is trying a Symbotic warehouse and that Walmart has installed several. Gahagan allowed that what he called the "red" cola giant—Coca-Cola—is using two Symbotic distribution centers. ("It was tricky with the unions, but they've made it work.") Now, he said, Coke's main competitor, the "blue one"—Pepsi—wanted to try the system.

"If someone can start a warehouse with automation and sell for less, everyone else has to follow," Gahagan said. "Consumers buy on price, so the cost on the supply chain matters. Walmart, it made a very efficient supply chain and that's why it was able to offer the lowest prices in its stores, so everyone else had to compete. And now you're seeing that happen with automation."

He observed that technological innovation has been happening in one way or another for a hundred years. Tractors replaced manual plows, but we were now able to produce much more food, he said; A.T.M.s replaced tellers, but banks still employ hundreds of thousands of people. "Imagine placing a phone call when you had to have someone place a wire into a socket for you," he said. "Being on a switchboard—those were good jobs. Every time technology has evolved, yes, individual people are impacted. . . . But the standard of living has gone up. I'd rather be in the world we're in today than

a world without computers, without cell phones, a world without elevators."

We walked onto a platform where we could see a track on which the mobile robots were lined up, waiting to be called into action. Occasionally, one of them would whirr its motor and blast off, like a little rocket. Gahagan looked down on his robot army with affection and awe. "Depending on who's in the White House next, you get to the fifteen-dollars-an-hour labor or twenty dollars an hour?" Gahagan said. "I'm voting for a thirty-dollar-an-hour minimum wage. That'd be fantastic marketing for us."

If the fully automated warehouse was a structurally different entity from its precursors, what about the fully automated factory? Gahagan had pointed out that other countries were embracing industrial robotics more aggressively than the United States was. I saw the scale of this during a recent trip to China. One steamy afternoon, I boarded a bus in downtown Shanghai and headed south along the Huangpu River, far from the city's noodle shops and glittering luxury fashion emporiums. About half an hour later, I reached a vast, low building, where hundreds of bicycles were parked in a covered lot. Inside, I was greeted by Gerry Wong, the C.E.O. of Cambridge Industries Group, which manufactures telecommunications equipment—more than three million items a month—for companies such as Huawei, Nokia, and Alcatel-Lucent. Wong grew up in Beijing, studied electrical engineering at M.I.T., and worked at Bell Labs for fifteen years. He started C.I.G. in 2005, and says that the company produces between two and three million products each month. He has the air of an excitable gnome, with a mop of black hair, thick seventies-style eyeglasses, and a wicked laugh.

Wong sat with his back to a wall of dozens of screens, which depicted various production metrics and live video of the manufacturing floor, where workers—and an increasing number of robots—were fabricating circuit

boards. (I was there on a trip with a nonprofit called the China-U.S. Exchange Foundation.) He quickly demonstrated the lack of sentimentality with which many businesspeople in China approach the subject of automation. C.I.G. is trying to replace as many human workers with robots as possible, he explained. Three or so years ago, the company had thirty-five hundred people at work in the factory. Two years ago, it was twenty-five hundred. Today, it is eighteen hundred. Over the same period, he said proudly, the company's output had doubled.

"China's labor costs are increasing, or doubling, every few years," Wong explained. "We are actually overcoming the difficulty by increasing our efficiency, through automation." For Chinese businesses, Wong said, lean manufacturing must include industrial automation, and they couldn't make it happen fast enough.

Much of China's economic power during the past two decades came from its position as the manufacturing engine of the world, but in the past several years its growth has started to slow. China was never a particularly convenient place for Western companies to have their sneakers and T-shirts and widgets made; the main allure was cheap labor. With Chinese wages increasing sharply every year, though, manufacturing there has become less attractive, and the Chinese government is devoting enormous resources to making the country the automation capital of the world.

As we put on gowns, hairnets, and cloth shoe covers in preparation for entering the clean manufacturing area, Wong elaborated on China's need for swift automation. There was a labor shortage, he said, exacerbated by the longstanding one-child policy. And, as the population has become wealthier and the cost of living higher, fewer people were willing to do manufacturing work.

"We are pushing all industries to go to all automation," Wong said. And the

employees seemed compliant. “Probably they don’t care very much, not like back in the industrial revolution, in Europe, where they would go and destroy machines. That was the old days.”

“They leave, anyway,” Rose Hu, a brisk, blunt woman who works as C.I.G.’s senior vice-president of marketing, said. “Every Chinese New Year, almost eighty per cent of the people, they will not come back. You have to have new.”

We passed through a pressurized air lock that blasted away whatever dust or lint we had on our persons, and entered the clean part of the plant. Rows of orderly white machines, tended by workers wearing what looked like chef’s hats, were moving circuit boards through the assembly line. Robotic arms, behind windows, were doing most of the work, while the mortals did tasks that required fine motor skills, like plugging tiny components into place. Every now and then, a cute little robotic trolley came ambling down an aisle, playing Mozart to alert the humans that it was approaching. (Until recently, most industrial robots were separated from human workers by steel cages, to protect the workers from injury. Now robots that can work alongside humans without harming them have come into use.) Two workers hovered at a workstation and jammed connectors into holes in a line of circuit boards before sending them into a glassed-in chamber, where robotic arms soldered the pieces together.

“There were thirteen people doing this. Now we have only one or two,” Hu said, gesturing at the two workers, one man and one woman, both young adults. “Before, we used people to solder. We used to have sixty-three people to finish one thing, and as of last year we need only sixteen people.”

The circuit boards continued down an automated conveyor belt. Other robots placed stickers on boxes, before a group of humans moved in to place the circuit boards in the boxes, along with packing materials. “Closing the

box—this is for some reason hard to automate," Hu said, shaking her head.

Each time I asked about what happened to the displaced workers, Hu and Wong waved away the question, amused at the predictable direction of my inquiries. Hu insisted that factory workers would simply find another place in the economy, such as the service sector. "We already went through several industrial revolutions—and we still have a job!" she said. "I think it's people who haven't lived through the industrial revolution who don't understand this. The world changes. You constantly have to improve yourself to keep up."

Later, back in the room with the surveillance monitors, Wong gave me a slide show on the history of industrial revolutions. The first phase began around 1800, in Wong's rendering, when the steam engine came into use, and was based in Britain, France, and Germany. The second phase, in 1900, saw the advent of electricity, and was centered in the U.S., the U.K., and Germany. The third was the information-technology revolution, beginning in 2000 and concentrated largely in the U.S., Germany, Japan, and Korea. Wong's point was that China intended to be at the forefront of the fourth phase, which would center on integrating robotics and artificial intelligence. Finally, he put up a slide that said "The future: 'Dark Factory.' "

"You don't need workers, you turn off the lights," Wong explained, chuckling. "Only when an American journalist comes in we turn on the light."

Stefanie Tellex, the roboticist at Brown University, grew up in a conservative Catholic family in a suburb of Rochester that abuts Lake Ontario, where, she says, "everyone's got a house and a yard, and there's no crime." Her father was an accountant; her mother taught second grade in downtown Rochester. Tellex became interested in computers as a child. Her father gave her an old DOS 486 when she was in grade school; her aunt, a

programmer, supplied books of simple coding exercises. Tellex was admitted to M.I.T. and planned to pursue a liberal-arts degree, but her mother told her that liberal-arts graduates didn't make any money. ("One of the best pieces of advice I've ever gotten.") She completed her computer-science Ph.D. there in 2010. She said that "The Jetsons," the sixties-era animated TV series, helped spark her interest in robots.

"When I think of A.I., that's what I think of, the robot," she said. "There's a scene where they're drinking smoothies together, the mom and the robot, who has a relationship with the family, but on the show she's a servant. And she can do everything you can do."

After Winnie completed its petal-plucking tasks in Tellex's lab, we sat down in her office. She told me that she had never thought about the political implications of her field until the tense months leading up to the 2016 Presidential election. Her parents were Trump voters, and she found herself disagreeing with them about what the causes of society's ills were, and what the best solutions might be. She was alarmed by the anti-immigrant sentiment emanating from Trump's rallies, especially having spent her adult life surrounded by researchers from all over the world. Economic inequality was a driving theme of the election, and Tellex began to see that automation was a contributing factor. The economy was generating wealth, but almost all of it seemed to be going to the wealthy. The official unemployment rate has dropped to 4.2 per cent in the United States—its lowest level in ten years—and the economy is expanding, but wages for most workers have scarcely budged.

In 2015, the Princeton economists Anne Case and Angus Deaton identified a surprising data pattern that reflects these economic fault lines, finding that mortality rates for middle-aged white non-Hispanic Americans with only a high-school diploma have been increasing since the late nineteen-nineties.

They attribute this trend to "deaths of despair" tied to the long-term loss of economic opportunity, particularly blue-collar jobs, and to possibly related factors such as opioid abuse. Deaton listed globalization, immigration, and technological change as likely factors behind the decline of middle-income workers and the related rise in inequality, but noted that, in the developed world, stagnant wages and an associated increase in death rates were unique to the United States. "The political explanation is the one that seems to make most sense," he told me. What does he worry about if these trends continue? "How about pitchforks?" Deaton said, laughing awkwardly. "I mean, I don't think this is stable politically. The Trump thing is probably just the beginning."

Tellex has been conducting her own research into the causes of income inequality and, with her friends, has amassed a reading list of academic studies and news articles. She is drawn to the idea of a universal basic income, in which citizens would receive enough money from the government to cover living expenses. Ultimately, she knows, blue-collar workers are not the only ones who may need such economic assistance. The disruption spurred by automation is not anticipated to be limited to low-skilled work; significant encroachments are expected in the white-collar sector as well, with experts predicting that professionals such as accountants, doctors, lawyers, architects, teachers, and journalists will all compete with increasingly capable computers in the future.

There were ways, Tellex believed, to mitigate the effects of rising inequality without vilifying immigrants or blaming technology. "I'm one of the few people among my friends who regularly talks to Trump voters," she said. "There's enough money for everyone, I keep telling them—there is. It's just not in your pocket, it's in the one per cent's pocket. If only we had the right progressive tax system, this wouldn't be such a problem. As a roboticist, I feel a responsibility to communicate this to people."

For twenty years, Steelcase's Corporate Development Center was housed in a futuristic pyramid-shaped building, which cost more than a hundred million dollars to build. It became a landmark of the Grand Rapids area; employees returning home from business trips would proudly make note of it as their flights descended into the Gerald R. Ford Airport. In 2009, in the midst of the financial crisis, Steelcase moved out of the building. It sat vacant until 2016, when a company called Switch moved in. Switch is a third-party data center, and plans to house giant servers there for companies like Disney and eBay.

Dave Stinson, at Steelcase, told me that he often became emotional when he saw the building, and was reminded of what it represented. "It's especially cool at night, when the lights are on," he said, as a loud beeping forklift sound echoed in the background. "I'm getting sentimental. It's a monument for our city. There was talk that they were going to tear it down. That would have been a huge loss."

After decades on the factory floor, he's seen enough workers laid off to know something about losses. Bill Sandee, his colleague, tries to put those losses in perspective. "It was rough to see some of them leave," he told me, referring to the waves of laid-off colleagues. "Some of them, their jobs were being eliminated because they just didn't have enough work. And the company has to do something to survive. But it's hard not to take it personally when you're losing your job. You have to go home and tell your wife and kids, 'I'm out of work.' I remember one engineer saying, 'I won't be seeing you anymore, Bill, I just got RIF'd.' It didn't feel very good." He paused. "Let's face it, if you love somebody, you care about 'em. So many things in our lives are out of our control."

That didn't feel very good, either. Stinson described the time, months before the Presidential election, when a friend asked him which candidate he was

supporting, and he said, "I'm not voting for another Bush, and I'm not voting for another Clinton. Period." The night before the election, he and his wife attended a Trump rally in Grand Rapids, in the heart of a state that Hillary Clinton had expected to win comfortably. More than four thousand people lined up for blocks to hear Trump at a downtown convention center. Stinson said he decided that night to vote for the Republican ticket. "The way I voted was based on the idea that we're not losing jobs anymore, we're not doing the NAFTA thing," he said. "I hope he fulfills what he was trying to do when he was campaigning and it's not going to be all broken promises."

He was accustomed to politicians disappointing him. Robots hadn't yet. Stinson used to spend his days reminding workers of what they were supposed to be doing, or trying to figure out how faulty parts had sneaked into the system. He used to jump in and demonstrate precisely how a screw was supposed to go in, or whether the torque was correct. Now none of that was necessary. Automated machines were driving everything. "As opposed to having to train, train, train, train, train, making sure you're getting the muscle memory right," he said. "It was hard, it was stinky, it was 'I gotta check everything.' "

Back when the factory floor was thick with workers, they used to bicker, and Stinson says he was constantly dealing with the drama of their personal lives—there were illnesses and feuds and car accidents. No longer. The crews are thin; the pressure is less. The youngest of his three sons, aged thirty, works in a different department at the Steelcase plant. He had dropped out of college, hit hard by his grandfather's death at sixty-five, and Stinson said he had encouraged him to go back to school or go into plastics. Still, he said, "He's happy here."

Stinson says he is, too. He explained that his line's productivity had shot way up—from a hundred and fifty desk legs a day a year ago to an average of

eight hundred a day, and growing—which made him feel good. "That's a lot of butts in a lot of seats," he said. When I asked how many new workers Steelcase had hired to accommodate the increase in production, he said that workers were mainly being moved between production lines, to replace workers who had retired. The company was about to install two more automated workstations, though, to "accommodate this and future growth."

He gazed out at the smoothly functioning factory floor, the rows of machines diving and pecking in front of their human minders, performing a kind of dance. Even if the economy stayed strong and demand remained high the head count was expected to decline through attrition, year after year. "It's got all the technology that you could possibly think of," Stinson told me, when he showed me the vision table. "Until next week, when we find something else that we could change to make it better." Automation was bringing greater and greater efficiency, even though, at a certain point, the logic of increasing efficiency would catch up with him, and he wouldn't be around any longer to witness it. One day, the factory might go dark. In the meantime, he was enjoying the advantages of work that involved less work.

"There were times when I thought I could do something else besides this, you know?" he said. "I really like the job a lot better than it was. Now I don't feel overwhelmed anymore." ♦

An earlier version of this article misstated the monetary value of the trucking industry in the United States.

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