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The Rise of the Machine: How Industrial Robots Will Revolutionize U.S. Manufacturing

Alexander Koontz

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By

Mr. Alexander Koontz

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Thesis Advisor T.E. [signature]

Dr. Tomás Estrada

Second Reader Mark M. Gatti

Mr. Mark Gatti

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Abstract

Automation has become a term to symbolize many different movements in today's world. It could represent anything from the blind, preprogrammed robotic arm in an automotive assembly plant to the increasing prevalence of driverless cars on the road. It could be used as a word of praise in the chase of more efficiency and optimization, or as a curse against the aspect of the obsolescence of humans as their roles are rendered redundant by robotic laborers. However, the lack of clarity of the term stems from a lack of understanding about its historical connotations, precisely how it applies today, and what it might mean in the future. I believe that we can draw from examples in the past and apply their lessons to the present to determine the best possible course for the future. The history of robotics, and more broadly the increase in optimization that led to their development, will provide the backdrop of the grand drama by which the present will play out. The current state of the field will provide the context for much of the analyses of how the future should play out. The future will be conjectured into a few key paths, all of which are possible and plausible. It is a matter of what is done now that will determine what path will be the most likely. Before the future is set, let's examine how the present came to be.

Historical Background

The closest historical relative to today's idea of a robot would most likely be the automaton. While these machines were not designed to do useful labor, but rather to accomplish some artistic task, their built-in functions and simple movements puppet what would be found on industrial machines hundreds of years later. The most notable example of an automaton to survive into the modern era would most likely be Maillardet's writing automaton, currently on display at the Franklin Institute in Philadelphia. The automaton itself can imitate the motion of a person writing with a pen and paper on a miniaturized desk. This capability is possible because of a simple mechanical memory that's hardwired into the automaton by a series of cams and levers [1]. The cams themselves serve to store the memory of the movements necessary for the automaton to successfully execute its instructions. While it is not the traditional computing process used to execute the movements of modern robots, it is a simplified example of a machine executing prewritten instructions for it. The cams and mechanical memory are complex enough to be able to produce four drawings and three poems [1]. This is a small feat compared to the capabilities of today's machines, but it serves as a notable demonstration to how humans were dreaming of ways to use machines to perform tasks that were once thought to be the exclusive domains of humans long before the advent of the technologies that would make it much more feasible. However, automatons were unable to do useful work necessary for their widespread adoption. Much like the wheellock mechanism in firearms, they proved too complex, too delicate, and too expensive to maintain for most applications. However, the advent of the steam engine proved to be how the automation movement would gain traction in conscious thought.

Perfected by James Watt in the 1700s, the model of steam engine he used proved to be the workhorse that would power the innumerable factories and mills of the first industrial revolution [2]. Where human labor was confined beforehand in scale to the exertions of draft animals, the steam engine allowed a much greater scale of work to be accomplished. This is the first sign of increasing automation, as draft animals were gradually phased out in favor of machines in all applications of life. This is self-evident, as one only has to look outside to see that cars are present instead of carriages, tractors sow the fields instead of oxen pulling a plow, and electric motors and pulleys provide rotary motion for production operations instead of some form of animal labor. However, these systems still required some degree of human input. While widespread automation of labor had caused some job loss, as evidenced by movements such as the Luddites in industrializing Britain, people were still required as machine operators and to process the inputs and outputs the machines were dependent on [3]. So, this first automation of labor and movement away from traditional modes of industrial production is not fully comparable to the problems that we face with modern automation. However, another historical theme that developed out of the industrial revolution, and one that is very prevalent today, is efficiency.

Industrial and Economic Concepts

There needs to be a clear distinction drawn between the similar concepts of efficiency and effectiveness. Effectiveness is how well a task is completed, while efficiency is how economically a task is completed. As a blatant example, take the case of a person having to move a boulder up a hill. If they decide to roll it up and have the strength to do so, then they have effectively accomplished their task. However, if they use a handcart to move it up the hill with less effort on their part, they were no less effective with a greater amount of efficiency since they expended less effort. If the same person uses a truck to move the boulder up the hill, their effectiveness remains still unchanged. However, their efficiency is the greatest out of the three possible cases. The first industrial revolution accomplished the task of increasing both effectiveness and efficiency. More goods were able to be produced than was previously possible because of the better capabilities of machines, and in a much more efficient manner due to the ease with which machines are capable of accomplishing work compared to humans. However, the efficiency by which humans interfaced with machines was sorely lacking. As another example, assume that a boiler can reach an infinitely high temperature with more coal shoveled into it at higher speeds. If humans are used to stoke the coal, there will eventually come a point where they will be unable to continue due to exhaustion, too much heat coming off the boiler, or some other combination of factors which renders them ineffective as stokers. However, there are several options to remedy this situation. Instead of forcing the stokers to throw coal into the boiler with shovels from a distance away, moving the piles of fuel closer to the boiler would trim time from the stoking process. Or, equipping the stokers with refrigerated suits so they could tolerate the high temperatures for longer would solve the heat issue. Or employing a secondary team to take over for a short while and give the main team breaks would prevent heat exhaustion. The multiple solutions to the problem, as well as the path to finding the best combination of solutions, is what gave birth to the profession of industrial engineering. It is my belief that tools utilized by industrial engineers can be used to augment human labor instead of replacing it with the continuing automation that affects the workforce today.

As the industrial revolution progressed, several key concepts would become prevalent which would form the basis of automation efforts in the future. The most famous example would be the division of labor into smaller, manageable tasks. With current technology, a machine cannot puzzle through a complex task on its own without assistance from a human operator or by simple computer algorithms. However, the likelihood of a task being accomplished increases when it is broken down into simpler movements. The concept of the division of labor was most famously illustrated by Adam Smith in *The Wealth of Nations* when he outlined how the process of making a pin can be broken down into a series of simple tasks. He outlined how when each overall goal was broken down into tasks and the tasks were assigned to individual workers, overall productivity rose [4]. Instead of relying on the quirks and skills of individual craftsmen, standardizing tasks and training workers so they become very good at a simple step in the process would make workers both interchangeable and much faster at accomplishing their part. This was further explored using therbligs in motion and time study [5]. Therbligs are categorizations of simple movements used to accomplish a task. They can vary in scale ranging from the movement of a forklift in a warehouse to the eye movement of someone as they execute an assembly task. Traditional industrial engineering has relied on observation and timing analysis to determine the optimum therbligs needed to accomplish a set task in a factory. After a goal was divided into smaller tasks, these tasks would be divided into smaller therbligs then optimized from the level of therbligs upward to find the best possible way to accomplish the overall goal. This concept of optimization works with both humans and machines, but the principles of standardization were also a key set of components of the revolution in industry which can be applied to how automation should be approached in a modern perspective.

Standardization was the engine by which the industrial revolution accomplished its rapid proliferation and adoption by nations across the globe. Without standardized parts and means of measurement, industrialists would have been hard pressed to find sources for replacement parts and means by which to apply quality control to the products they produced. It began with the standardization of screw thread measurements, from which more complex and precise production machinery such as lathes and shapers were able to be reliably constructed [6]. More precise production machinery allowed for more accurate quality measurement tools to be produced, which cascaded into even more precise production machinery. This effect allowed for rapid growth of the means of production and the means of measuring production quickly and efficiently. However, like the previous boiler example, the main source of bottlenecking in terms of production capability came from human elements. While machines could quickly and accurately accomplish tasks, their human operators could only set up production jobs and measure the results in an indeterminate and unstandardized amount of time. Modern automation efforts also seek to alleviate this through the installation of automatic quality control systems and automated production machinery like CNC mills. But while standardization and the division of labor have extremely important parts to play in future automation, the principles of scientific management will also have a lot of say in determining the precise path that automation will take in the future.

Scientific management was founded to optimize processes while maintaining cost-effective procedures. The school of thought can be mainly attributed to Frederick Winslow Taylor, who proclaimed that innumerable resources were going to waste because of the inefficiency of industry at the time [7]. While this statement was about laborers being underutilized from their true potential, I believe this same principle can be applied to the setup of industry and modern supply chains today. This was very clearly demonstrated when a single supply ship blocked the Suez Canal in March of this year and cost the global economy approximately $6.7 million per minute it blocked the causeway [8]. Supply chains have become too nebulous and delicate, especially when presented with an unexpected occurrence. Applying principles of scientific management to automation efforts in industry with a particular emphasis on economy of motion and time in task accomplishment should lower the cost of doing business where the costs of labor are higher. This would make more localized supply sources for manufacturers and retailers more viable in the United States, as well as more resilient to unexpected global occurrences such as a trade disruption in the Suez Canal. Additionally, applying the principles of scientific management and optimization to supply chains in general should simplify them to the point where they are theoretically more resilient to such disturbances. However, while tools such as scientific management and optimization can easily be applied to real world cases, it should be noted that robots and AI have been portrayed in popular science fiction for decades before they became even a remote possibility. I believe that older industrial engineering tools set the foundations for what automation efforts can accomplish, but the glamor and mythos behind fictional representation of robots needs to be dispelled to gain a clear picture of modern automation.

Portrayal in Popular Culture

While the term 'robot' was coined by Karel Čapek in a Czech play that was meant to name workers that had been produced by a company to function as their main labor force, it was later applied in a more general sense to any form of mechanized labor [9]. This is no more evident than in *I, Robot* by Isaac Asimov. The advance of technology moves from huge robots the size of a room to models like Speedy, a robot with a deliberately human personality that was capable of functioning on the surface of Mercury [10]. They gradually move from crude programs incapable of only basic human interaction to forming their own religion surrounding their work. The human traits in the short stories are always explained away as quirks in their programming, but there is always the slight what-if of whether it truly is their programming or whether the robots are forming their own consciousness. While the stories are responsible for establishing the Laws of Robotics that have engrossed science fiction readers since and given personality to otherwise blank constructs, the fiction they present is far from realistic. I do believe that we will move closer to systems that are designed with human interactivity in mind, as well as streamlining robots to make them more accessible and useful for humanity. However, I do not believe that programming is variable enough to develop the types of human-like quirks as seen in the stories. Additionally, the Laws of Robotics have too many loosely defined concepts that cannot be quantified in programming. This could quickly lead to paradoxes or prevent the programming from executing like intended. So, while Asimov's stories about robots exhibiting human-like quirks are entertaining science fiction, the probability that the way he imagined robots functioning will ever be anything but fiction is extremely unlikely. Another example of a popular depiction of a robot in fiction that has formed the modern perception would have to be Marvin from *The Hitchhiker's Guide to the Galaxy* series.

Marvin the android is deliberately designed to have a human personality [11]. While Douglas Adams wrote him to be as deliberately depressing as possible, his character is the most likely occurrence for the path that interactive automation will take in the future. While designers most likely will not design their robots to be permanently dejected and act like every task they undertake is a huge burden, programming in basic personality features would allow humans to connect and control them more easily. Once humans form an attachment to an object, they are more likely to be open to utilizing the object's features and learning more about how to interact with the object. Programming in a distinct personality with signifiers that would signal a user what they should do and how they should interact with the machine would be a large step in the direction of integrating automation into life without forcing it [12]. While I do not foresee personalities being as complex or with a distinctly nihilistic theme like Marvin's, I can see how the general concept of giving machines and automated systems engrained personalities would drive up acceptance of them in both the workplace and society at large. While *I, Robot* and *The Hitchhiker's Guide to the Galaxy* both provide excellent illustrations of what robots could possibly be like in the future, with doses of unrealistic expectations, the development of industrial systems and crude automation efforts from the 1940s to today provides a much clearer picture of what automated systems in general may look like instead of individual robots.

Historically Automated Systems

The most notable move towards automation in industry from the 20th century would have to be the advent of CNC machines. While machine tools originally depended on human operators to conduct their processes, the mid-20th century is when punch cards began being used as a crude form of programmable control for machining applications [13]. The proliferation of microprocessors and computer control in the 1970s began to supersede punch card programmed CNC machines, particularly with CAD software coming into vogue in the past few decades [14]. While machine operators are still needed to set up the jobs for the machine and ensure that it will run correctly, their role has largely been converted to overseeing the process instead of directly participating in it. The benefit of this automation has been that it allows parts to be duplicated in precisely the same manner every time, if the program remains unaltered and the machine is in good working condition. This is also a good example of how I believe automation should be implemented, with human roles being made easier and their effectiveness being augmented by machines rather than being completely replaced by machines. Another notable example of the proliferation of automation in industry would have to be the automated quality control systems that have been put in place.

Ensuring the precise and accurate application of quality control programs has always been a challenge for industry. Efforts for consistency among human workers led to many of the great industrial programs of the 20th century including efforts by pioneers such as W. Deming, Walter Shewhart, and Henri Fayol [15]. While much of the emphasis on quality control was embraced abroad by rising nations in the East such as Japan, the United States started focusing more on quality control efforts in the 1980s and 1990s with the advent of Six Sigma and more ease of access to automated quality control equipment [16]. Quality control equipment can be adapted based on available sensors as well as process tasks to detect many variables in products. Controlling for time in process, physical position, surface finish, quantity of liquid held, components in place, and correctly executed modification operations are only a few examples of how sensors can be implemented into production. If the sensors determine that a product's characteristics fall outside the prespecified parameters, it can either alert the machine operator or divert the faulty product away from the main processes for examination by the quality control department. This saves the time and effort of quality control personnel in having to go and physically gather samples of defective specimens, as well as machine operators in potentially having to unjam the machines, customer service personnel having to deal with defective products, and shipping personnel in having to process an order going out and a defective one coming back. As another example of how automation should be completed, machinery has been used to augment humans instead of replacing them. This example also illustrates my next point, in the importance of controlling environment for automated production processes.

Production environments are already tightly controlled areas, ranging from yellow lines painted on the floor to determine where it is not safe to step to the computerized inventory systems that allow shipping operations to be efficiently conducted out of one location. However, I would argue that for automation efforts to be as successful as possible, care needs to be taken to control for physical environment as much as possible, even more than is currently done. As an example, say that a company implements an automated inventory system of robots that move around a warehouse area to pick and place products. If they were to implement such a system, the entire warehouse should be off-limits to all human personnel except for inspectors and repairmen. The warehouse should control for temperature and humidity to prevent premature part degradation, and periodic inspections of the physical facility should be undertaken to prevent physical building degradation from affecting the automated systems. The robots themselves should be networked to prevent collisions, as well as having both a primary and secondary means of navigation such as line following sensors and ultrasonic sensors to ensure proper functioning should one fail. The lesson to be drawn from this outline is that with less unexpected occurrences happening, automated systems of any kind should run smoother. However, this is also dependent upon the design of the automated system being optimized for its application to begin with, so care should be taken to ensure that optimal industrial efficiency is reached for the initial implementation and design. Easy adaptability and upgrades to system components should also be accounted for in designed systems. With all this taken into consideration, an examination of the current market for robotics and automation is in order.

Current Trends

The COVID-19 pandemic has had a drastic effect on automation efforts in the United States. While industry generally saw a downturn in demand due to declining economic conditions, demand for automation of services increased [17]. Increased global economic tensions led to a reexamination of the potential for reshoring industries in the United States, of which automation would play a large role in making the move feasible. Additionally, increased demand on ecommerce sites such as Amazon led to a spike in demand for automated warehouse systems and services. This compounded the already growing industry, which is now projected to be worth triple in 2027 what it was in 2019 [17]. While China is currently the biggest market for automation, I project that the United States and other emerging industrial powers will surpass China's demand for industrial robots and automated systems as they rush to localize their economies. COVID-19 exposed the delicate nature of the global economy, incidents like the Suez Canal blockage only exacerbated it. New developments in automation will also contribute to how quickly it is widely adopted in industry.

As technology evolves, automated systems will see a concurrent evolution in their design, implementation, and widespread usage. One of the largest developments in automation would have to be cloud computing, as this allows automated systems to more accurately track, monitor, and store production data for assessment by quality control specialists and inventory programs [18]. This ties factory systems more closely into the supply chain and allows for greater overall control of the production process from start to finish. Another would probably be the production opportunities offered by automated machinery. While human personnel require breaks and more stringent workers' rights, machinery can run however long it needs to. This opens a larger production-possibility landscape that would have previously stagnated because of the inherent limitations of human workers. Another, more recent advancement would have to be the degree of control with which robots are able to accomplish tasks. Due to sensor implementation and more precise automation equipment, the cost of robots have fallen as much as 50% compared to human workers since 1990 while gaining in precision during the entire time [18]. This has allowed the cost of labor for machines to fall while the quality control capabilities have risen. The speed and processing power of computers have obviously increased the entire time as well, along with software proliferating and becoming more user-friendly. As such, robots and automated systems have become cheaper, easier to implement and use, and more adaptable than ever before. While it was previously outlined how robots have become useful to this current point, and how we should not project unrealistic expectations onto them based on optimism for the future, the potential realistic future uses for them are numerous and exciting.

Future Industrial Applications

The most likely direction that robotics in industrial settings will take in the future is as general-purpose machines that can be retrofitted for their specific tasks. Machines tend to increase in popularity and decrease in price when they are constructed to be used by as large a population as possible. As such, designing bots and automated systems to be used by as many industries as possible with little relative change in the processes used to manufacture them will allow for the most possible customers to be cultivated. Making the bot designs modular to allow for easy repair and upgrades will make it much easier for the designs to stay implemented and relevant to industrial production. For example, say that a company sells a baseline model which is a simply powered chassis with rudimentary navigation programs. You can program it to travel from Point A to Point B on a predetermined route. All bots are designed this way from the factory, but you can pay more to have more additions added. These could include more sophisticated navigation systems, extra limbs to manipulate and load objects onto the bot to carry, a larger hold to transport items, or maybe an attached controller so an operator can use the bot remotely to accomplish tasks. The more modular and interchangeable these upgrades are, the greater share of the automation market the manufacturer will hold. However, there will always be some market for more specialized bots in industry that general purpose ones simply cannot fulfill.

Currently, most automated machinery systems in the market are robotic manipulators [19]. These emerged in the 1940s and have grown in popularity and ease of use since. These manipulators spawned the more specialized machinery that was used to automate American factories in the 1960s and 1970s, such as the automatic paint appliers in GM's plants. Currently, a large portion of demand for robots in industry is composed of these specialized forms [17]. However, with Amazon's increased use of general purpose work robots to pick and place in their warehouses, demand for general purpose bots has skyrocketed in the past few years [17]. As such, I would estimate that demand for specialized bots will continue increasing for a few years, then decrease and plateau while smaller firms invest in more general-purpose bots for their operations. Another potentially lucrative market for robotics and automation would have to be hazardous work.

One of the primary benefits of automated systems is that human lives are inherently not put at risk when substitute machines are used for hazardous work. This could be in industries ranging from mining to hazardous waste disposal. One of the original applications of robotic manipulators in the 1940s was to handle radioactive material safely away from humans during the Manhattan Project [19]. Explosive ordnance disposal robots are widely used by police squads and the military to remotely dispose of bombs, so they pose little risk to personnel or civilians. Robots have been used to explore the ocean at depths that would pose a hazard to humans. So, while automation has much to offer in terms of efficiency for accomplishing work as well as speeding up processes, it can offer a route to safely accomplish dangerous work that would otherwise be a risk to humans. While production environments would obviously benefit from increased automation, the warehousing industry can also be streamlined through automation efforts.

Future Logistics Applications

The main goal of warehousing is to be able to stock just enough product to serve customers on demand while minimizing logistical demand on owned facilities. Automation is in its complete element in this case, as the entire supply chain process is dependent on accurate reporting of numerical variables. These range from quantity of product shipped out to how to optimize shipping, so an exact number of products are shipped out together with as little wasted packaging as possible. Implementing AI inventory systems in multiple levels of the supply chain would increase collaboration between different supply chain partners and simplify the ordering and shipping process. Additionally, if warehouses are fully automated with logistical robots and an overseeing inventory program, they can theoretically run without human intervention beyond occasional maintenance. Allowing this process to continue would cut one of the main expenses in industry, storing and transporting product until the time comes for it to be sold. This would improve both service for the customer and profitability for the manufacturer. The transportation sector shows great potential for automation as well.

Self-driving cars and trucks have gained an increased presence in media and industry as production giants such as Tesla and Volvo rush to increase their vehicles' capabilities. While this has resulted in fatalities and crashes along the way, such as Tesla's famous problems with their semiautonomous steering system, the gains made in recent years present a very optimistic picture for the future [20]. While truly autonomous traffic systems are still most likely decades away, autonomous vehicles could sharply cut down on the prevalence of driver injuries and fatalities due to human error. Additionally, automated transportation systems for goods such as forklifts, trucks, or ships could free up human resources to pursue different endeavors while the more mundane work of transportation is accomplished by software and computerized systems. It may even progress to a point where humans work to design a product, but the manufacturing, transportation, storage, and distribution of the actual goods are all handled by automated systems. While such advances are some way off, and it will most likely be piecemeal advancement instead of all at once, the potential for such technology to become the norm presents an interesting challenge for engineers to tackle in the future. More pure scientific endeavors also offer an opportunity for engineers to sharpen their skills while using automation to provide a valuable service to society.

Future Scientific Applications

Space exploration is one of the most exciting and conjectured about opportunities to use robotics and automation. Since space represents such a hostile environment to unprotected biological life, robots and autonomous probes are obvious choices to send in for exploration before putting human resources at risk. This goes back to the hazard mitigation argument in favor of automation. Additionally, autonomous probes can store and transmit mass amounts of data about extraterrestrial environments back to Earth for analysis and planning future missions. While missions such as the rover missions to Mars are the most recent examples of such a line of thinking, there remains a broad opportunity horizon to expand over. If rovers to study environments can be dispatched and controlled from Earth, why can't digging and autonomous construction machines be dispatched to other planets and satellites and construct bases for future astronauts? With new technologies like 3D printing and recent advancements in materials science, building materials can be manufactured locally using equipment imported from Earth and assembled into scientific facilities. Theoretically, the CAD and CAM files can be created back on Earth and transmitted to the construction drones to modify their constructions with minimal lag. Colonization efforts can then leapfrog off each planet as humans send bots further out into the galaxy, then colonize each planet or satellite they prepare. While the bots and automated systems may not be fully autonomous, they will prove to be a great tool for allowing humans to accomplish work in environments too hazardous for humans to explore directly. The field of human-machine systems interfacing is also seeing a rapid expansion of robotics and automation technology.

One of the biggest barriers to widespread adoption of robotics and automation has been the lack of simple human-machine interfaces. As an example, hobbyist robotics has been a niche interest since the 1970s, but really only exploded in popularity in the past couple of decades with the proliferation of easily programmable microcontrollers such as the Arduino and Raspberry Pi [21]. High level programming languages such as Python and Java were not readily available back in the 1970s and 1980s either. With their much more intuitive UI and easily understood code, they have grown in popularity for automation as well as programming in general [22]. If this trend continues, modular programming languages that rely more on moving around virtual blocks representing code functions may rise in popularity. This will open access to programming tools to an even larger portion of the population, which will subsequently increase the advances being made in programming and automation efforts. So, while programming languages will increase in capability and proliferate, a natural side effect will be individuals choosing to automate aspects of their lives instead of investing energy in mundane tasks. If nothing else, this dissemination of programming knowledge and capability will increase interest in technological and scientific advancement, allowing for more people to enter technologically based fields earlier in life. So, while the advancement of programming languages to more intuitive UI and easier programming principles may be mundane to most outside of the niche community that follows such things closely, it may prove to be more impactful long term than other, more publicized advancements in automation and robotics technology. While this all of this is exciting news, there are several ways technologies like this can impact the wider world.

Means to Approach Automation

The most obvious effect, and the most controversial one, of automation would be the immediate negative effect on jobs and employment. Advocates for workers' rights claim that automation will threaten to destabilize the power balance between labor unions and companies. Additionally, while automation may help reshore jobs that were previously exported to countries with lax labor laws and cheap labor to offer; there is widespread fear that automation will simply automate people's jobs out of existence as they are replaced with algorithms that are cheaper to implement and more adaptable to run. Machines do not need wages, breaks, or regulations for their safety and wellbeing in work environments. This fear extends further than the manufacturing sector, as software such as automated tax services offer serious competition to tax firms that have not developed them. People are afraid that there simply will not be enough jobs to go around compared to the amount of people present that need them. There have been a variety of motions to remedy these fears, ranging from people advocating for regulation of the technologies to politicians such as Andrew Yang advocating for a Universal Basic Income which guarantees all Americans a monthly stipend from the government [23]. While these theories of what will happen when automation fully arrives are conjecture at this point, they do have some merit based in history. However, a full examination of the possible utopian benefits offered by widespread automation is to demonstrate why some people are so dedicated to ensuring its proliferation.

Automation offers benefits in what was previously discussed, such as removing humans from hazardous and injuring work, proliferating and expanding technological possibilities, and speeding up the supply chain process to allow people to gain access to needed materials and goods at a much faster and more predictable rate. It offers humans a chance to build a tool by which to explore the universe and gather data for future expansion into the stars. It also offers a means by which people can be freed up from the mundane nature of their jobs and give them more time to be spent on leisure and personal expression. Automating jobs that provide little stimulation to their holders and offer little real economic gain for the company is the best move for everyone involved [24]. However, utopias have a way of never materializing. The very real fears offered by the opposition to automation movements have a strong grounding in history, such as the actions of industrialists against union organizers in the 1800s that often ended in bloodshed. With a balanced approach to automation efforts that stresses more of an augmentation role for new technology instead of worker replacement, I believe that the best aspects of automation technology can be achieved while protecting the autonomy and rights of the worker.

If the government provides incentives to automation companies to offer technologies that focus on augmenting the capabilities of human workers and complementing human workforces, I believe that the benefits of automation can be reached while preserving workers' autonomy from companies and their source of income. Much like how the much of workforce shifted from agricultural workers to urban factory workers during the industrial revolution, the automation movement will cause the roles of workers to shift from what they once were. Government programs that foster technological education and provide incentives for people to gain technical training would provide a means for people to shift from low-wage, low-education labor to higher paying and more dynamic technical roles. Instead of moving crates around a factory, workers can be better utilized to setup and control machines that do it for them. While there will not be full role shifting or conservation, I predict the economy will grow enough and new companies will open that will provide jobs for the displaced. Additionally, I predict that widespread automation will drive up demand for handcrafted goods and will stimulate a small return to something like cottage industries. While people will generally be happy to consume the cheaper mass-manufactured goods offered by automation efforts, they will simultaneously desire goods that are custom created for them. Smaller, non-automated producers will be able to offer these goods at a slight premium above automated manufacturers. Automated logistical systems will be able to deliver these handcrafted goods alongside mass-produced ones. So, I do not believe that the gloomy dystopia predicted by protestors against automation will come to pass. Nor do I believe the utopia that extreme proponents of automation predict will exist either. Instead, with enough government intervention and pressure from consumers, a movement more geared towards augmentation of the workforce instead of replacement of the workforce will prevail and create better economic conditions for all. My personal experience at experimenting with a small model of an automated system is evidence that this technology will proliferate, but it needs to be properly managed to prevent its misuse.

Personal Experimentation

Due to the pandemic, I was unable to construct a prototype autonomous bot from scratch, as I did not have access to the necessary tools to do so. However, I purchased and assembled a small kit off Amazon that had semiautonomous capabilities for modeling purposes (Figure 1). It has an ultrasonic sensor for obstacle avoidance, a line-following sensor to differentiate and follow either a dark line on a light background or a light line on a dark background, and an infrared module for remote control capabilities. Imagine this bot can function as a "forklift" in a scale model of a factory. Even with the extremely basic and cheap sensors the model uses, it has a wide range of capabilities as a material hauler. You could program it to simply follow a line painted on the factory floor and stop when it detects an object in front of it with its ultrasonic sensor. Assuming the factory has a hauling route that is a simple loop (such as Figure 2) Shipping & Receiving puts raw materials onto the cart as it passes by and delivers the materials to Manufacturing. Manufacturing offloads finished goods onto the empty cart as it passes, which empties it back at Shipping & Receiving. Conversely, assume the factory setup needs to change on a relatively regular basis. One could turn off the line following capability and put it in obstacle avoidance mode only, then line the route the cart must follow with solid barriers. If the sensors are working properly, the cart should avoid the solid barriers on its route and still complete the circuit. If the barriers are easily moveable, like plastic Jersey barriers, the loop can be continuously changed to suit the needs of production. This also provides another safety mechanism for workers, as it provides fodder for the cart to hit if it malfunctions instead of people. Lastly, the remote-control capability would allow workers to manually move the material hauler at will if they would need to. This would be the best safety mechanism, as one would not have to depend on potentially temperamental technology to provide full safety for the workers. But this case demonstrates that even with relatively crude sensors and basic programming, multiple opportunities for cheap automation have presented themselves. Additionally, these automation methods do not directly replace anyone but augment manufacturing and shipping capabilities. If a programmed Kanban system is implemented with stops at certain workstations for required materials on demand, the factory could embrace Lean and on-demand manufacturing principles much more readily than without [25]. With more sophisticated software engineering and more expensive sensor setups, the potential for automation of tasks to cut production time offers much in terms of time and labor savings. I believe that this will only increase with the proliferation of modular and easily modifiable production and automation technologies.

Modular robotic design was briefly touched on earlier in this work, but I firmly believe it to be the most important concept outlined. With the widespread access of miniaturized microcontrollers such as Arduinos, the opportunities for amateur automation have never been easier [26]. While they may not have the capabilities of their more expensive cousin, the programmable logic controller (PLC), they do have a fair amount of capability for their cheap cost. Coupled with cheap motors and manipulator kits compared to more expensive industrial counterparts, I believe that the world will see the rise of small-scale automation movements in the next few decades. While they will lack the brute force of industrial motors and setups due to cost, the flexibility of these cheap systems will allow them to be much more widely implemented [27]. This may allow smaller firms to get access to automation equipment without the associated cost of having to pay an official manufacturer, as well as being able to modify the equipment with modular parts at will. While this idea is currently only popular with amateur roboticists, I believe that the increasing popularity of DIY technology will move it to the forethoughts of many people in the business world [28]. Time will tell whether I am correct, but I believe that modular augmentations to human workers will ultimately outnumber the more specialized and less flexible robots that most people picture when they think of how automation will replace the human worker.

Industrial engineering concepts from the first industrial revolution, such as the division of labor into simple tasks, standardization, and scientific management prove just as useful for automation now as they did back when they were first created. They provide a framework by which automation can be implemented to complement the human workforce instead of directly replacing it in production operations. Additionally, the rise of more accessible technology that allows people to experiment with and mix and match electronics for different purposes will prove to be a key factor in the proliferation and creation of new automation technologies in the future. While efforts at automation face an uncertain future due to a variety of factors, I believe they offer the best possible means by which to deliver a more sustainable and streamlined economy than any other current movement.

Appendix: Assorted Figures

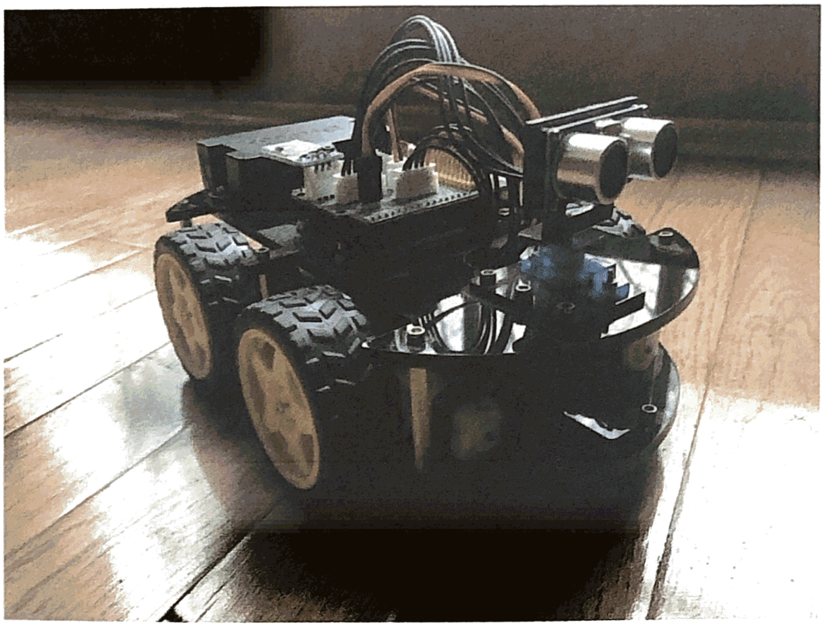

Figure 1: Assembled Test Bot

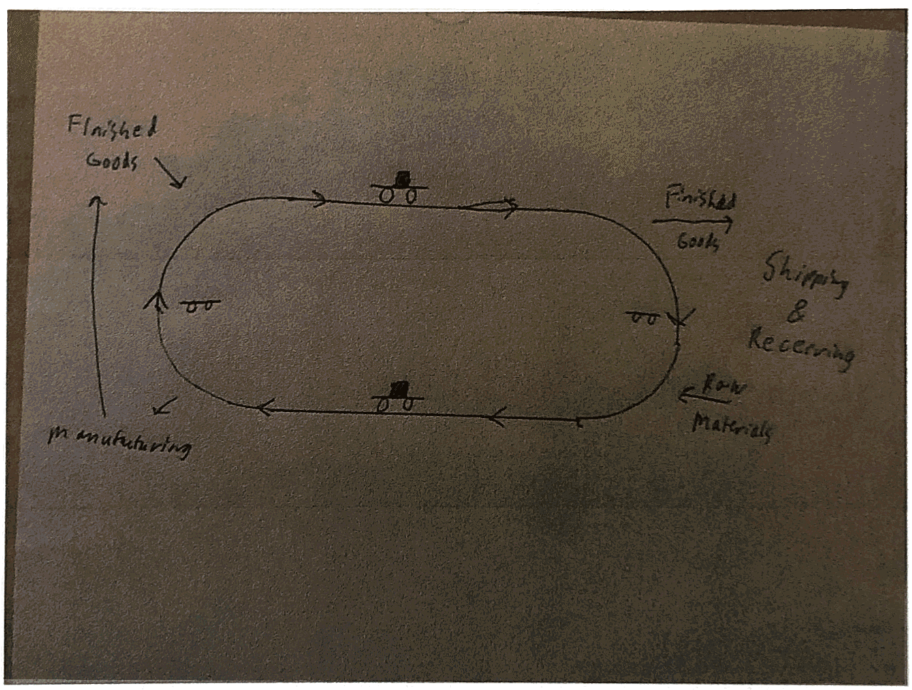

Figure 2: Basic Production Loop

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