Automating a Manual Mill Press into a Computer Numerically Controlled Machine

The Impact of Automation and Artificial Intelligence on Society and Policy

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

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Automation is the application of machines used to perform various production processes that were once carried out by humans without human intervention. While the prospect of mass job loss is an ominous side effect of automation, the better prepared and informed we are as our society progresses into the next stage of industrialization can make the transition more seamless. My technical research and my loosely coupled STS research at their core both relate to automating a process in order to increase efficiency, productivity, and profitability. For my technical research project, my team is converting a manual mill press used for cutting blocks of metal into a CNC (Computer Numerical Control) machine which automates the milling process in order to execute its cutting in each X-Y-Z dimension. For the STS research portion of my project, I will be discussing how this goal relates to automation and will evaluate the further implications it will have on our society over the next several decades. My focus will be weighted on specific industries that experience the most dramatic changes as a result of automation such as Manufacturing, Transportation, Healthcare, and Agriculture, as well as the sentiments and effects on social groups who are most heavily affected by this next wave of industrialization.

Technical Project: Converting a Manual Mill Press to CNC

For the technical research project presented in this paper, I am taking part in a 6-credit machine design experience for the duration of the fall 2020 semester under the guidance of the Mechanical and Aerospace Engineering Department's Gavin Garner as my advisor. My team of 5, James Pincus, Isaac Buell, Lucas Pompeo, John Cooper, and myself, are converting a Precision Matthews PM-727V Milling Machine, which is a manual bench stop mill press used for cutting different kinds of metals, into a 3-Dimensional CNC machine. By achieving this automation, the process of cutting a shape from a block of metal can be interpreted through a computerized set of commands sent to the machine to perform the cutting instead of having a person physically operate the milling machine.

Figure 1: PM 25MV-BD Mill Press. Retrieved from Precision Matthews company website.

The purpose in developing an automated CNC device onto a manual mill press is to gain a hands-on experience in replicating the same way these machines were developed to be used by manufacturers. As opposed to a manual mill press, CNC machines are far easier to use in the long term, assuming the operator has the expertise and training to operate its software. When a mill press is automated, the process becomes much faster, requires less physical human labor, and delivers a far more precise cutting process at a much lower cost. While early CNC machines in the 1940s and 1950s used punched tape primarily for telecommunications and data storage, modern machines have evolved to cut just about any material ("The History…", 2019). CNC machines compose a significant area of expertise in the present-day manufacturing economy and are still growing. The global market for CNC machining was worth $70 billion in 2018 and is projected to reach $111 billion by 2026, marking a staggering growth of 58.6% over six years ("How are…", 2020).

Project Objectives

For the project, the primary area of work required to achieve this transition is implementing an Ethernet SmoothStepper system (ESS), as shown in Figure 2. This system is connected to a computer or router and controls the motion of the milling process by accepting commands from CNC software Mach3/Mach4. As opposed to a USB SmoothStepper System, the ESS does not require the use of a PC with parallel ports. As described out on the Warp9 Tech Design website, this system is the link between the machine and the software which drives its toolpath ("Mach3 Software", Undated). The group's collaborative effort in converting the manual mill is taking place in the Mechatronics Innovation and Learning Lab (aka "The MILL"). This space, located in the basement of the University of Virginia's mechanical and aerospace building, is dedicated to SEAS Undergraduates as an advanced manufacturing makerspace by offering a plethora of tools and machines to work with and manufacture various items. My team is fortunate enough to be able to work on one of the multiple mills, manufactured by the company Precision Matthews, described above that are used in the MILL. We have spent the semester researching the machine and the necessary steps needed in order to carry out a successful conversion. At this point in time, we have disassembled several main components of

Figure 1: ESS Motion Control Board with Terminals for Mach3 & Mach4 Software. Image taken from Amazon.com.

the PM-727V mill and are working to have all the parts required to add on ordered and delivered to the MILL.

We are still replacing the standard lead screws from each axis with ball screws instead, which each will be driven translationally by their respective motors. The source of power which control the position of the plates mounted to the X-Y-Z ball screws will come from two Clearpath 3421 motors and a Clearpath 342S motor. These Clearpath motors are a popular choice in CNC machining because they can be controlled very easily with step and direction pulses. Ball screws provide a mechanical advantage over lead screws as they can transmit and deliver a significant amount of power while requiring much less torque input than traditional lead screws. Because ball screws have grooves similar to a bearing running through a helical semi-circle groove down the shaft, they have much lower friction and can run at cooler temperatures. However, a disadvantage to ball screws is the effect of "backlash", which is caused by space between the ball bearings and screw grooves resulting in lost motion of the screw ("How can I…", n.d.). Following the disassembly of the machine's main components and removal of lead screws, we found appropriately sized motors and a power supply for them. We have also determined a necessary ball screw length and have had them delivered from a quality vendor. We are now looking to understand the connection between the ESS Breakout board with the motor drivers. We also will order and install new couplers which are used to connect the motor driveshafts with the ball screws, transmit torque between them, as well as remove backlash. Another key design process taking place is creating mounts for the motors which will be added to the machine. This will be done using SolidWorks CAD software on a Windows computer. We also plan to run a finite element analysis (FEA) on our design to determine what shape is necessary to withstand the potential force generated by the machine in order to avoid failure.

Once the design is finalized, the mounts will be cut from a block of isotropic aluminum using an identical spare Precision Matthews machine also located in the MILL. In addition to using these added components, one of the final, but most important steps in building the CNC machine is to install limit switches underneath the base plates of the machine in order to prevent a motor from moving past the travel range of its respective axes. The switches begin operating when a moving component of a machine makes contact with an actuator, activating the switch which opens or closes the circuit to its respective motor. The switch then regulates the electrical circuit that controls the machine and its motors. These are a crucial safety component of the machine as they are operated by humans. If the machine lost track of its physical limit and attempted to operated its toolpath beyond the physical range of its axes, it can potentially seriously injure those nearby.

Once these steps have been carried out, we hope to have made a successful conversion of a manual mill to an automated CNC machine. The rewarding aspect of this project is learning the machine's inner machinations and knowing that the MILL will offer students the use of a fully functional CNC machine that was constructed on grounds. I plan to further research the historical practices of milling machines in manufacturing as well as previous mechanical design aspects and iterations in order to justify the implementation of our specific machine components through writing a scholarly article.

STS Research Topic: The Impact of Automation and Artificial Intelligence on Society and Policy

Motivation & Accelerating Effects of the Pandemic

The goal of my STS research aspect of this project is to address the fundamental effects that society will experience as a result of automation and artificial intelligence (AI). While societies have undergone different stages of industrialization at different rates throughout history, the natural technological advancement of the next wave of automation will drastically change how businesses and organizations function at an unprecedented rate. There is an increasing collective sentiment of apprehension about the future as automation directly and indirectly relates to job displacement, as some rate of adoption is inevitable if it makes companies more profitable. While the pandemic has helped people more broadly accept its use by making things safer for businesses and consumers, it has accelerated the rate of adoption by accommodating to the safety guidelines of COVID-19. Businesses were adjusting to new lockdown measures and social-distancing guidelines in order to preserve the ability to deliver their products and/or services in a safe way. Throughout the pandemic, industries have been adapting to these new ways of life through increased automation. These implementations show further implications of how automation will affect the workplace in the future.

While COVID-19 has accelerated impacts it will have on our workforce, people are more willing to accept automation than they were pre-pandemic because it has helped businesses keep their employees and customers safer (Corkery & Gelles, 2020). However, labor and robotics experts suggest that "social-distancing directives" will drive different industries to accelerate automation in some form post-pandemic as well. In the same article, Clemson University Professor Richard Pak explains that "people become more expensive as companies' revenues decline". While some industry leaders claim that introducing robots and leaning on automation will aid essential workers and decrease their heightened workload during the pandemic, companies may no longer have a need for the same workers post-pandemic if the automation truly is here to stay. McKinsey & Company reports that many executives agree that since the start of COVID-19, the rate of adoption of digitization and automation of technologies has rapidly increased (Cheng, et al., 2020). Nearly half of the 800 executives surveyed by McKinsey reported increasing their adoption of automation, and roughly 20 percent have significantly increased its use in their organization.

The prospect of automation and AI has initially alarmed many workers and technology experts in fear that advancements would cause devastating levels of job loss. However, the understanding of where the next industrial revolution is heading is now much more complex and ambiguous as there are benefits and unknown opportunities to be provided as well. I am aiming for my research to look backward in recent history to provide context of automation from the past several decades, as well as look forward in assessing the current and future trends that will affect both people and communities. This analysis will also address misconceptions on the subject of automation and AI and provide a thorough overview of suggested federal, state, and local policy actions to be made in order to minimize the negative effects of this next wave of industrialization.

STS Framework and Application

The workplace as we know it is permanently changing across all industries. Artificial Intelligence, automation, and robotics are becoming more prevalent in an effort to transform the efficiency of manufacturing, services, and informative decision making. Many jobs will become obsolete, many more will be created, and almost all current jobs will transform in some capacity. AI is one of the most polarizing topics in the technical world as it has the potential to learn theoretically infinite amounts of information at an unprecedented pace. Provided an idealistic version of AI is achieved, being one that can learn on its own by interpreting outside data and making informed decisions with full autonomy, is something that could fundamentally change the world economy as it is smarter than the average human and can work and make decisions much faster. With its theoretically limitless ceiling of intellectual capability, only creative and non-automatable maintenance jobs may remain after that point. Peoples' sentiment towards the acceptance and adoption of automation and AI in some form shows the interpretive flexibility of its technology in that its innovation, rate of adoption, and design process will be influenced based on how it affects different social groups.

Breakdown of Significantly Impacted Groups

In order to successfully navigate and prepare for these rapid changes of adoption across all industries, especially while exacerbated by the pandemic, a social construction of technology model (SCOT) must be developed. The model in Figure 3 shows the problems that various

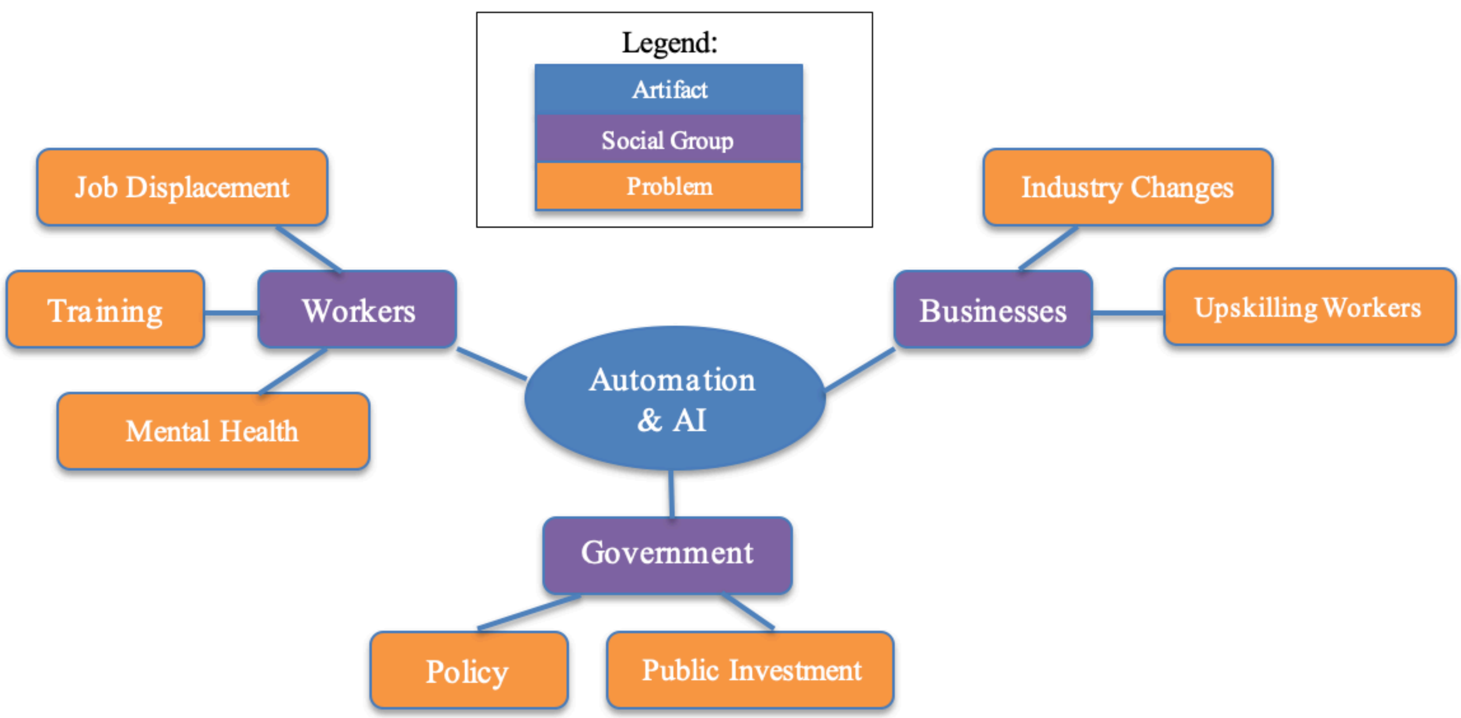

Figure 3: SCOT Model for Automation and AI. The graphic shows the relevant social groups impacted as well as problems to be addressed in order to better prepare for the adoption of new technologies. (Adapted by Ben Stein from Bijker, Bonig, & Oost 1984).

social groups face as our economy continues down the path of adoption towards automation and AI.

Effects on Workers

Before generalizing job displacement as a direct symptom of increased adoption of automation and AI, it is important to assess its interplay with human labor in order to understand the interaction of machines and workers. The Metropolitan Policy Program at the Brookings Institution, a Washington D.C.-based research group, lays out six general tendencies of how automation will impact workers:

- **Automation substitutes for labor.** Machines that can perform tasks currently done by humans will be done with a higher level of precision, speed, and for less cost.
- **Machines substitute for tasks, not jobs.** Since a job is a collection of tasks, machines will only be able to handle specific tasks performed and not an entire human job in an organization, even under the most advanced projected scenarios of technological advancement.
- **Automation also complements labor.** The tasks that are left for humans to perform will increase in value as a result.
- **Automation can create jobs by increasing demand.** Some sectors may actually increase employment as the machine substitution of labor can lower costs as well as improve the quality of the product.
- **Augmenting capital and labor leads to innovation.** Humans have more time to create new products and roles if repetitive, time-consuming tasks can be performed by machines.

- **“Technological possibility” does not equal “technological reality**”. McKinsey & Company estimates that just 18% of the United States’ “digital potential” will be reached. We are projected to fall short due to factors such as “technical feasibility, deployment challenges, regulatory and social barriers, and institutional factors, among others.”

With that being said, there are clear challenges workers will face that must be addressed. The fear of job displacement is as valid as it is common. Manyika and Sneader of McKinsey & Company (2018) predict that around 15 percent of the global workforce, or 400 million people, could be displaced between 2016 and 2030 as a result of their current roles being automated. They note that this figure could be up to 30 percent of people under their fastest adoption scenario. On the other hand, various cycles of innovation throughout history have led to job creation as well.

The research firm Forrester estimates that 331,500 net jobs will be added to the workforce in the United States next year (Press, 2019). However, while we do know that new jobs and tasks will emerge as technology advances, we are unsure how many will be created and where because the demand for certain roles will change due to evolving task demands. History provides context to this claim. From the 1980s to the 2000s, half of employment growth emerged from occupations that did not exist previously (Muro et al., p. 20). However, as automation progresses into the new AI era, the same authors predict that automation will likely continue to have a “muted net impact” on total employment due to various limitations of machines. While some jobs are lost as less human labor is required, as innovation progresses, higher paid workers are affected more frequently, but lower paid workers will suffer more deeply and experience longer periods of unemployment (Bessen & Kossuth, 2019). Welfar programs such as unemployment insurance are framed as a way to cover these losses, however, HBR's data confirms this lost income is not nearly covered. These spells of unemployment affect both peoples' financial stability and overall wellbeing.

Even if the roles of many workers will only be partially automated and not entirely displaced, their mental health will likely be affected as well despite keeping their job to the nature of how their role changes. The low-to-medium-income employees' roles are most highly affected in that the majority of their tasks that are clearly defined and repetitive will become automated will take on a more overseeing role with varying periods of activity intertwined (Hewitt, 2017). This will interestingly result in work that is more tedious, yet mentally fatiguing, as Hewitt explains. It is true that models in cognitive psychology, neuroscience, and economics indicate that mental and physical effort is draining. However, in 2017, researchers monitored the effect of effort and boredom on subject's brains using electroencephalography (EEG). Their study suggested that subjects who performed more boring tasks repetitively actually experienced more fatigue in the long run and those who exerted more effort in their tasks given through the course of the study (Hewitt, 2017). Boredom has been linked to significant health problems, such as cardiovascular disease, increased anxiety and depression, and increased use of recreational drugs in some populations. Due to these findings, we should further evaluate accelerated automation's effects on peoples' wellbeing and performance in order to altruistically develop a more informed and benevolent implementation framework.

Effects on Businesses

Businesses are currently making the role of automation and AI a priority in order to remain competitive and significantly cut their operational costs. More specifically, automation broadly describes the process of performing a repeatable task by a machine, and AI is used to analyze data, improve customer service, automate production, predict performance, prevent outages, etc. While all industries will be transformed as technology advances, some will be more severely affected than others. The potential for implementing automation is highest in industries such as manufacturing, agriculture, mining, and large service sectors such as retail and food preparation (Muro et al., 2019, p. 35). The jobs that are most severely in decline are lower to middle-wage jobs which involve more repeatable tasks, making them more susceptible to adopting automation. Examples of these jobs include factory workers, office staff, and various information technology (IT) roles (Muro et al., 2019, p. 24).

Another challenge that organizations will face at an increasing rate as the landscape of the workplace transforms due to technological innovation is the need for retraining and up-skilling their workforce. Upskilling is defined as "the process of teaching employees new skills that will aid them in their work" ("what is upskilling…", n.d.). In order to have the staff with the necessary skills required to use new technologies, completely automating certain tasks and retraining existing employees must occur in order to remain profitable and competitive. World Economic Forum founder and executive chairman Klaus Schwab emphasizes the significance of being proactive in this process:

> "It is critical that business take an active role in supporting their existing workforces through reskilling and upskilling, that individuals take a proactive approach to their own lifelong learning, and that governments create an enabling environment to facilitate this workforce transformation. This is the key challenge of our time" (Chowdhry, 2018)

The World Economic Forum's Future of Jobs Report in 2018 projected machines to perform over half of current human work tasks by 2025 as opposed to the 71% being performed by humans at the time of the report (Chowdhry, 2018). The report also determined that 54% of employees that are a part of larger organizations would need to upskill in order to adequately adopt this growth potential. The responsibility in retraining and upskilling employees heavily lies on organizations and is intersectional with their workers and governments as well.

Effects on Government

The advancement of automation and AI will certainly impact the way government aids, regulates, and interacts with entities which use this technology. The Metropolitan Policy Program at Brookings outlines five key steps to be made on a federal, state, and local level in order to facilitate an "automation-resilient" employment strategy. These initiatives will support the broad implementation of novel technologies that drive innovation, increase productivity, and ultimately foster future job creation. Figure 4 shows the progression of these steps:

Figure 4: Progression of policy implementations for mitigation of negative impacts on workers as a result of automation. (Adapted by Ben Stein from Muro, Maxim, & Whiton 2019)

The purpose of the first step in embracing the development of transformative technologies is to catalyze growth by prioritizing tech-lead productivity gains. Productivity growth will unquestionably increase the workers' average output, allowing companies to reduce their prices and increase their market share. This allows for an increased salary paid to workers and a higher standard overall. In order to achieve this, the federal government must increase R&D funding on automation and AI in order to ensure America's competitiveness in the technology sector as well as effective and humane development (Muro et al., 2019, p. 50). The second step in promoting constant learning can be achieved through investments in upskilling workers, expanding accelerated learning and certification training programs as well as making it more financially obtainable, and adapting education to align with technological innovation. The third step addresses the need to reform the United States' lagging adjustment system. This can be achieved on a federal, state, and local level through implementing a "Universal Adjustment Benefit" in the form of periodical stimulus checks given to aid displaced workers. Hiring efforts can be maximized through subsidized employment programs as well (Muro et al., 2019, p. 56). The fourth step focuses on providing relief to struggling low-income workers, particularly those in the service industry, through reforming and expanding income support systems as well as lowering the volatility of wages for low-paying jobs. These jobs commonly lack sufficient access to basic benefits such as retirement, paid leave, and health insurance (Muro et al., 2019, p. 62). The final step is to alleviate the burden placed on local communities and help provide a sustainable foundation for implementing new technology. Local labor markets vary considerably, depending on how much automation affects them, and directly shapes the average work standards for communities. This instability can be mitigated through programs which brace vulnerable regional economies and expand their ability to adjust to new innovations. The government can help firms become more resilient to automation by providing frameworks for adoption.

One of the most unique candidates of the 2020 United States Presidential election was Andrew Yang. Yang was one of the first mainstream proponents of providing monthly stimulus checks, even before the pandemic existed, to American citizens in order to ease the financial hardships of those hit hard by the next wave of automation. His platform incorporated a Universal Basic Income system and emphasized that we should focus on the next wave of automation due to its unprecedented projected rate of job displacement ("Andrew Yang Warns…", 2019). He foresees the issues that the next wave of automation and AI poses on many Americans and why politicians need to take technological progress more seriously, especially when considering how COVID-19 has accelerated job automation in order to accommodate social-distancing directives.

Summary of Research and Analysis of Further Impacts

My STS research project will be a scholarly article addressing the impact of AI, automation, and robotics on society, and how our historical perceptions will contextualize and further affect its implementation. I also aim to outline in more detail how the policy decisions in our government can protect various social groups from the next wave of automation and AI by elaborating on the steps that were provided.

The specific fields discussed in the paper will be changed long-term and with a recession expected to follow this pandemic, companies will likely no longer have a need or want to employ many reassigned workers. The similar trends in industries already affected by automation are now being accelerated with new remote and automated approaches being applied to the workplace. More specifically, I plan to delve my research further into several highly impacted industries such as retail, tech, and transportation, and assess various cases to contextualize how different social groups are impacted demographically by this technology as well

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