Applications and societal implications of artificial intelligence in manufacturing

Artificial intelligence (AI) technologies have many potential applications throughout manufacturing operations and management. Depending on how they are designed and deployed, by whom, and to what ends, AI technologies could advance or undercut economic prosperity, economic equity, job accessibility and quality, environmental health, and public safety and security. Responsible development and implementation of AI will require open deliberation and broad participation in setting the objectives and forms of AI technology, with explicit efforts by technologists, funders, regulators, vendors, users, workers, and civil society to shape industrial AI to public purposes.

Manufacturing applications of artificial intelligence. The Organisation for Economic Co-operation and Development (OECD) has defined AI as "a machine-based system that can, for a given set of human defined objectives, make predictions, recommendations, or decisions influencing real or virtual environments."[1] AI can be achieved using techniques such as machine learning (including deep learning) and applied to purposes such as natural language processing (including large language models) and robotics. In industry, AI can be used for design, planning, tracking, and control at several different scales of manufacturing operations; AI is especially powerful when integrated with other forms of automation and digitalization, including robotics and smart factories. For example, AI could permit robot arms to seamlessly manipulate diverse types of work in progress and self-program in response to context. These robots could be designed to safely assist workers, enhancing their productivity and flexibility, or helping with heavy tasks; or the AI-enabled robots could be designed to replace as many tasks as possible, leading to potential job losses.

Other manufacturing applications of AI include generating or assessing designs for tools or products, speeding the development process, or enabling novel design features. AI process monitoring, fault diagnosis, error compensation, and predictive maintenance could enhance process reliability, increase process speed, reduce downtime, or reduce consumption of materials and energy. On the level of supply networks, AI might be used to coordinate production schedules in accordance with changing conditions, to automate supply purchasing, predict input or output prices to guide purchasing and production, track inventory, or analyze customers and anticipate their orders. Applications like these could potentially increase the flexibility and agility of supply networks, reduce redundancy within supply networks, or increase firm competitiveness and profitability. Jobs such as purchasing and production scheduling are currently performed by managers and other white-collar and service occupations, indicating that tasks and processes both on and off the manufacturing shop floor can be enabled and impacted by AI.

As these examples suggest, the benefits of AI in manufacturing may stand in tension with one another and with other societal values. AI may increase productivity and firm performance, but it may also require job redesign and added training, or even reduce the workforce required. It could help workers by eliminating mundane work but add other routine tasks. AI might reduce resource or time costs but also lower system reliability or resilience. The design of AI systems themselves, as well as the ways in which they are operated by firms and industries, will determine who captures gains and who might lose out.

Potential implications. The possible effects of AI in manufacturing cut across values of economic prosperity, equity, environmental sustainability, and security and safety, among others (see summary of key societal implications in Table 1). Advocates presume that AI in manufacturing will raise economic

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[1]OECD, 2019. Recommendation of the Council on Artificial Intelligence. Available at: https://legalinstruments.oecd.org/en/instruments/OECD-LEGAL-0449

activity and productivity. Others highlight concerns, including that AI could cut both shopfloor and management jobs, facilitate surveillance and privacy harms, and intensify economic inequality and job polarization within regions and across nations. AI-enabled factory efficiencies and the tightening of supply chain couplings could reduce resilience. In terms of environmental impacts, AI could advance environmental goals by reducing waste and using resources efficiently. But processing large data sets and the complex computing algorithms needed to power AI could add to energy use. AI might also increase vulnerability not only to cyberattacks but also the misuse or appropriation of personal data. While AI could potentially be used to increase shop-floor workers' control over their own work schedules, it could also result in greater worker surveillance and management micro-control. Used to assist hiring or promotion decisions, AI could reinforce existing biases—or it could be deployed to recognize and overcome prejudice and enhance fairness. The same type of AI technology may serve some values while undercutting others—e.g., techniques for increasing productivity may also eliminate tasks, or improved worker surveillance may serve management interests while reducing job quality. In short, AI has potential both to advance or to undercut important societal values, depending on its design and implementation.

Table 1: *Potential societal implications of AI in manufacturing*

Potential benefits	Potential harms	Ambiguous effects
Economic productivity & resilience		
• Agility, coordination & resilience—Improved firm situational awareness & responsiveness • Productivity—Increase labor, resource, & energy productivity	• Resilience loss—fewer redundancies & slack in production systems • Knowledge hoarding—Disincentivize or inhibit knowledge & data sharing	• Increase importance of shared knowledge or data capital
Job availability & quality		
• Increase process flexibility & worker autonomy • Job stabilization or creation—added engineering, computer science, maintenance, or specialized shop-floor jobs • Customized training; on demand guidance. • Help with mundane or heavy work • Safety—increase monitoring, alerts, & automated safety measures	• Task and job elimination—shop floor & management. New routine tasks added. • Skill losses—Replace or alienate experienced, flexible & skilled workers • Loss of tacit knowledge gained through in-person training • Bias—Automate inequitable hiring • Surveillance—Increase worker tracking & analysis. More micro-management.	• Extend workers' working lives • Reduce education needed for some jobs • Uncertainty about time and approaches to train an AI-capable workforce
Economic equity & justice		
• Small-firm competitiveness enhancement • New pathways to jobs and economic development	• Job polarization • Knowledge capture—extraction of worker skills without equitable rewards • Microtargeting & manipulation • Monopoly or oligopoly exacerbation	• Reshoring of production • Urban-rural balance in economic development
Environmental Sustainability		
• Reduced waste, improved production yields • Resource use decrease & production and logistics energy efficiency increase	• Energy demand increase for computing • Rare earth mineral demand increase • Resource & energy use incentivization	
IT, Security & safety		
• Automation and smart factory systems easier to code and manage • Cyberattack detection & response facilitation	• Increased cyberattack & industrial espionage vulnerability • Disinformation	

Source: Summarized from authors' review of literature (see https://arxiv.org/abs/2308.02025)

Responsible innovation in the Georgia AI Manufacturing (GA-AIM) Project. The GA-AIM project is "a public-private partnership convened to activate an equitable AI manufacturing technology corridor hub across the state of Georgia, with spokes across the US."[2] In addition to upgrading manufacturers using AI and other advanced technologies, the project seeks to strengthen supply chain resilience, foster innovation and investment, and build an equitable workforce. GA-AIM's ambit presents not only challenges but also opportunities given the inherent flexibilities of AI technologies—as noted above, their ethical and societal consequences will depend upon how they are designed and implemented, the values implanted in them, who controls them and how open and understandable they are, and whom they engage, support, control, or displace.

Regulatory and policy frameworks set the contexts in which AI technologies are shaped and operated. Guidelines and codes developed by government, industry, labor, and other professional and civic society organizations also shape technology design, development, and use. Ideally, public regulation and investment should be designed so as to prevent development or application of AI in harmful ways, to incentivize inclusive economic development, and to maintain market competition and economic opportunity not only for large firms but for smaller ones and for workers. This is not a straightforward task, given the many interests involved in AI development and use. Moreover, the pressures of global competition encourage both public and private sectors to pursue fast-track approaches that downplay risks. Yet the protection and advancement of public values in AI adoption is not a task only for policymakers or civil society leaders. Managers in firms need to reflect carefully on how they will implement AI technologies and how they will generate value for their customers, suppliers, employees, and communities. Technologists and innovation intermediaries will also need to anticipate implications and consider the needs of companies, workers, and communities in design and deployment.

Many different methods may be useful for assessment and planning. Workshops and consensus reports drawing insights from professionals and researchers representing economic development, labor, sustainability, cybersecurity, and economic justice interests may be useful for goal setting and planning. Citizen consultations, focus groups, and deliberations may help to elucidate public views on, preferences for, and implications of novel technologies or economic plans. Prospective life cycle assessments and empirical, environmental research could help to elucidate environmental effects of novel technologies. Cybersecurity assessments and cyber-games could provide insight into cybersecurity vulnerabilities and solutions. Scenario development exercises may help to elucidate different potential outcomes of AI manufacturing, variables affecting its development, and technological, political, and economic strategies robust to a wide array of possible futures.

AI manufacturing has substantial potential to advance or to undercut public values. The technologies developed could be applied to enhance worker autonomy and earnings, empower and revitalize rural and marginalized communities, and strengthen economic flexibility and resilience. Or they could be used to replace workers, enhance the market and political dominance of large firms, cut corners in production systems, reduce the share of value-added captured by labor, and facilitate worker surveillance and control. Educational curricula and job placement programs could offer paths to fulfilling careers, or lead to precarious jobs, route trainees or their work out of Georgia, and fail to reach historically disadvantaged communities. Technology deployment services could help firms to generate and diffuse value, including benefits to employees, or enable firms to speed up job elimination and wage reduction. And economic development planning and research could drive investment in equitable social and physical infrastructure, education, and community-building, or reinforce existing inequities.

[2] Georgia Artificial Intelligence Manufacturing Corridor, 2023.

Importantly, outcomes can be shaped. The achievement of the GA-AIM project's aspirations will require continuous work by all personnel, using a range of methods, to align project activities with public values. Ensuring that AI manufacturing technologies are designed and deployed responsibly—through attention to responsible innovation and ethics – is critical across all of GA-AIM's missions. Responsible innovation will involve anticipating, reflecting and acting upon ethical and societal concerns, including those of equity, fairness, accountability, and transparency, raised by the incorporation of AI into manufacturing technologies, systems, and practices. To foster dialogue on these complex issues, we have identified a series of questions for key groups involved in GA-AIM and the design and deployment of AI manufacturing technologies (Table 2).

Table 2: *Selected questions to examine and guide societal and ethical outcomes of GA-AIM activities*

Roles	Selected questions
Technology developers, vendors & users	**What does this technology promise, and how will it achieve it?** • What are the various types of harms (e.g., resilience loss, task and job elimination, inequitable hiring, surveillance) that this system could cause? • Whom could the technology harm or adversely impact, directly or indirectly, along the supply, production, and consumption chains where the technology will be deployed? • How can the design and implementation of the technology be changed to avoid or mitigate harms, adverse impacts, and ethical and other responsible innovation concerns? • Who will own and operate the technology, and the resources on which it depends? Who will benefit? Who may lose? • Have data and models been examined for bias, privacy violation, and other societal problems? • How could others use the technology in ways that would undercut values of ethical and responsible innovation?
Educators, managers, curriculum designers, & job placement personnel	**Does education, training, and HR balance individual, employer and community objectives?** • How will current workers be affected? Who will be upskilled and/or deskilled? What worker tasks will change or be introduced? What can be done to ensure that good jobs result? • What training/retraining is being made available for current and new workers? Is it sufficiently long-term? How will these programs contribute to the goal of ensuring equitable and positive employment effects? • Are ethical and responsible innovation components included in training programs?
Extension agents and innovation intermediaries	**Are services contributing to equitable business and community development?** • Are services customized to ensure that all manufacturers, including SMEs, can participate? • Is deployment strategic, addressing long term business management, workforce, and innovation as well as immediate technological upgrading? • Are ethical and responsible innovation implications being considered from the start? How is technology deployment being tailored to avoid or mitigate potential issues?
Economic and community developers	**How can local and regional economies become more equitable, resilient, and sustainable?** • Are community leaders, business associations, and other civic groups engaged in dialogue about AI technologies, and how are concerns and aspirations being addressed? • Are opportunities being planned or developed to establish new diversified and sustainable manufacturing approaches? • How will underserved populations or communities participate and benefit?

Source: Authors' elaboration

This brief was prepared by John P. Nelson, Justin B. Biddle, and Philip Shapira – School of Public Policy and the Ethics, Technology, and Human Interaction Center (ETHIC^x), Georgia Institute of Technology, August 2023. It contributes to the Georgia AI Manufacturing Project's (GA-AIM) ethics and societal implications component, which aims to understand AI manufacturing's potential impacts on societal values and to provide recommendations for researchers, government, and firms to address those impacts. For additional information related to this brief, contact justin.biddle@pubpolicy.gatech.edu.