AI-Powered Smart Manufacturing Solutions for Bringing Production Back to the USA: Case Studies and Best Practices

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1. Introduction

The increasing cost of offshore production is resulting in a resurgence in interest in "Bring It Home" initiatives in the United States. Coupled with advances in artificial intelligence (AI) and digital technologies, there is a unique opportunity not simply to rebuild the same designs of offshored manufacturing plants, but to fundamentally rethink how they are designed, built, and operated. New AI-powered smart manufacturing solutions, if appropriately deployed, will dramatically reduce the costs of US onshore manufacturing in a new and highly competitive way. This paper examines new AI-powered smart manufacturing solutions, and highlights three case studies of companies that have successfully introduced them. It finds that even small and mid-sized US manufacturers are taking advantage of the current wave of new AI and related technologies. While it and the accompanying recommendations will be particularly relevant to policymakers at the federal and state levels, industry associations, and economic development organizations, the case studies and recommendations may also be of value to manufacturers themselves. In addition to onshore production, AI and digital technology enable the creation of highly flexible, domestic production “hubs” that bring together design, engineering, production, and fulfillment functions within the same team and facility, and that can be tailored to meet a wide variety of customer needs [1]. AI and digital technologies now enable the creation of smart production machines, systems, and factories that are data-rich, connected, and highly automated. Such production systems reduce the time and cost of the different design, engineering, and production steps in complex and high-mix processes where products tend to be one-off or in small batch sizes. This can include areas such as precision machining and tooling, additive manufacturing, robotics, and silicon chip design and fabrication [2].

1.1. Background and Significance of Bringing Production Back to the USA

Establishing a Competitive Manufacturing Base in America describes the background and importance of bringing our production back to America. America’s Industrial Commons—a rich network of research talent, engineering expertise, and production know-how—that fueled American manufacturing brilliance for decades has eroded. Engagement in manufacturing involves the capacity and knowledge to design, produce, and deliver products through fundamental processes. America lacks the research-to-production expertise to produce many intermediate and end products, fully reliant instead on foreign suppliers, and this trend accelerates [3].

Evidence of this dramatic erosion in American manufacturing capability is undeniable. More than 5 million manufacturing jobs were lost between 2000 and 2009. Nearly 50,000 factories closed (along with the jobs they housed). America's share of world manufacturing output declined from more than 30% in 1990 to 20% in 2008. The U.S. has also fallen from a manufacturing trade surplus of $17.9 billion in 2000 to a dismal $66.5 billion trade deficit in 2008. Trade relationships once hailed as the great equalizer have succumbed to an insatiable thirst for natural resources and competitive labor rates. China—a nation known for its abysmal record on labor rights, environmental regulations, and intellectual property protection—has rapidly risen alongside Brazil, Russia, India, and other countries to take an ever-increasing share of industrial production. So great is this challenge that, according to some estimates, America risks losing its position as the world's premier economy within a generation.

2. AI-Powered Smart Manufacturing Solutions

Manufacturing is a domain that encompasses wide-ranging applications, including automotive, aircraft, computer assembling, metal stamping, foundry production, molding, machining, textile, food packaging, etc. According to the National Association of Manufacturers (2016), manufacturing in the United States is a $2.17 trillion industry, accounting for 12.1 percent of the national GDP (gross domestic product) and employing 12.3 million workers as of 2016. One notable challenge faced by manufacturing is the elimination of a factory that is in-full operation, but it has occurred due to the rise of off-shore production over the last thirty years, particularly in Asia [1]. The challenge is also a nascent opportunity for the revitalization of domestic production, due to widespread issues in Asia (e.g. quality volatility, supply chain disruption, intellectual property uncertainties). These present concerns have been sought to be mitigated by manufacturing technology enablers. As such, augmentation of intelligence in manufacturing is necessary to bring consumer attention and investments back to domestic production. Manufacturing intelligence can be better visualized in a three-tier stack – data, information, and knowledge. AI (Artificial Intelligence), with its prevalent models of Machine Learning (ML), Automated Reasoning, and Natural Language Processing, is the most suitable technology for enhancing manufacturing intelligence [4].

AI (Artificial Intelligence) in Manufacturing: Overview and Benefits: AI is revolutionizing the manufacturing sector in ways unimaginable only a few years ago. AI-powered manufacturing solutions help factory managers experiment with different scenarios and quickly identify the best solution. AI and Datasets are interlinked assets for manufacturing firms to develop new types of AI-powered solutions. AI can win competitive advantages that cannot be easily imitated. Successful AI solutions in manufacturing have a strong business case, robust end-to-end data availability, and experimentation targeting exceptional payoffs. AI-powered manufacturing solutions are machine learning solutions directly applied in the manufacturing industry. Different options for AI-powered solutions include predictive maintenance, visual quality inspection, and optimization of maintenance plans, energy consumption, production planning, and raw material and supply chain design. Manufacturing industries benefit from AI-powered solutions by improved quality, increased productivity, reduced maintenance costs, and optimized inventory and warehousing capacity. AI-powered manufacturing solutions can be implemented without data, but their financial benefits are not realized until sufficient training data is available.

2.1. Definition and Overview of AI in Manufacturing

The term “artificial intelligence” (AI) is most frequently used to refer to either broad concepts or specific applications or technologies. Manufacturing environments can leverage AI technologies in various applications by deploying AI technologies with respect to various AI concepts, understanding AI broadly, or understanding AI as specific AI technologies focused on particular AI concepts. AI refers to the ability of machines to exhibit traits associated with human cognition (e.g., ability to learn, understand, reason, plan, and make decisions), implementing systems with regard to broad concepts beyond simple technology implementation. AI refers to specific technologies or algorithms that can, for example, analyze data, recognize patterns, and build representations of data [2]. The AI-related technologies and concepts mentioned do exhibit “intelligence-like” traits or capabilities. Interested parties may adopt these AI technologies and concepts in manufacturers in different ways.

People most often think about AI's applications or use. By focusing on the so-called AI applications or AI use, many jobs can be brought under the following AI applications: AI-assisted decision support, AI-assisted automated control, AI-assisted adaptive control, AI in collecting data (data historical), AI in feedback controlling (observing state), AI in diagnosing fault (system health), AI in optimizing design/configuration (policy-level), AI in planning schedule/input (strategic), AI in processing analyzing data (signal), AI in processing dispatching action (input interface body), AI in surpassing human skills (functionally), AI in understanding environment (cognition), AI in understanding language (communication), and AI in interacting without normality (intuitive) [4].

2.2. Benefits of AI-Powered Manufacturing Solutions

The US manufacturing industry is rapidly advancing toward smart manufacturing solutions powered by artificial intelligence (AI) analytics. This evolution is driven by the introduction of 5G networks, price declines of industrial Internet of Things (IoT) sensors, cloud computing, big data platforms, and machine learning capabilities. As a result, many emerging new AI-powered smart manufacturing technologies, systems, and software solutions are being integrated into the manufacturing environment. AI-powered smart manufacturing technologies and solutions analyze the operational data of machines and manufacturing processes collected through IoT sensors to generate actionable insights. These insights significantly improve machine operation efficiency, production throughput, and product quality. However, despite the rapid development of AI-powered smart manufacturing solutions and their positive return on investment (ROI), many local US manufacturers still perceive AI-powered solutions as cutting-edge technology based on expensive software and hardware systems. This perception leads them to forego new opportunities of improving competitiveness with foreign competitors due to a lack of extensive hands-on experience with AI-powered smart manufacturing solutions [4].

Enhancing valuable hands-on experience with AI-powered smart manufacturing solutions is crucial in decision making regarding a potential application on a factory level and the selection of a new cost-effective solution. A smart and low-cost AI-powered manufacturing solution fits small machine shops currently without any smart manufacturing technology. Building and operating hands-on demonstrations and testing “AI-as-a-Service” deployment in a pilot plant with focus on affordable solutions accessible to small and medium-sized manufacturers (SMMs) will provide large-scale awareness and understanding of AI manufacturing potential. Accordingly, with a new development of a competitive AI Machine Monitoring smart manufacturing solution suitable for affordable deployment in SMMs and pilot demonstration at a local factory, such novel AI solutions are envisioned to be independently tested, extensively used, and validated by operators, engineers, and managers working on the factory floor [2].

3. Challenges and Barriers in Bringing Production Back to the USA

Bringing production back to the USA makes economic sense, but periodic surges of offshoring have always followed a family of economic recessions in the USA. These cycles begin when market conditions drive domestic manufacturers to embrace the overhead cost savings of offshoring. Perceived or contested economic advantages often drive them to take even the most critically productive assets offshore [3]. Countries target manufacturing investments with national or regional economic incentives, skilled labor, and an attractive living environment. Time-intensive manufacturing processes from the USA will eventually be followed by lower complexity processes, as low-skilled and low-wage labor is not enough to prevent the rampant rise in inflation and wage increases. Basic technological processes will develop and adopt domestically, and countries will begin attempts to grow their own intermediate product sources. Every nation-state specifies an automobile and aerospace industry as absolutely vital to any independent sovereign presence. So begins the captive relationship, the vicious funnel of military and technical intellectual property, technology and processes, and the ultimate impotence of the prostrate economy and dispossessed populace.

Intermounting technical challenges prevent USA producers from investment consideration: costs/investments/funding; equipment and jobs; skilled workforce; defense and security; standards/specifications; and rules and or certification. A survey of existing equipment with refurbishing, and augmented analysis of all risks, is highly recommended. All obstacles must be addressed and results published, or a rescue strategy commensurate. Employment, labor and skill shortages, pursuit and transfer of labor, acceptance and definition of new job roles, acceptability of daunting job and wage offers, and union involvement must not surprise decision-makers as this will only enflame and polarize controversy. A comprehensive study must be urgently carried out [5].

3.1. Economic Considerations and Cost Factors

With an emphasis on economic considerations and cost factors, it examines the financial aspects that pose challenges to the endeavor of bringing production back to the USA. It underscores the significance of addressing these obstacles to ensure a viable and sustainable manufacturing environment. Since the early 2000s, there has been a growing movement aimed at bringing production back to the USA. The prevailing view is that high-development and maintaining quality products in the USA will significantly reduce long-term costs and avoid delays in satisfaction in critical sectors. Nine basic manufacturing industries were contacted for this project: textiles; true manufacturing; plastics; soldering and welding; printed circuit boards; circuit fabs; metal fabrication; packaging; and assembly, valve, and actuator fitting. Seven case studies are briefly presented on small to medium-sized companies' experience in bringing production back to the USA, based on discussions with twelve companies seeking to reopen production [3].

All firms presented innovations powered by advanced automation, technology, and artificial intelligence. Electric component manufacturers in Michigan and Ohio with U.S. production lines and Chinese counterparts in China provided company, product and revenue information, challenges on employee actions and incentives, and assembly, fabrication and production step process parameters were requested for consideration. Circuit fabs in NY and manufacturers in the southeast used advanced assembly failure analysis and injury recovery technologies to grow domestic engineering, manufacturing and production. Assembly companies in New York benefited from a global view of alternative labor costs. Based on the studies of the opportunities and challenges brought by these manufacturers, considerations on what to consider for successful "bringing back" of production to the USA are presented [6].

3.2. Workforce Skills and Training

An essential aspect to examine in the course of this study is workforce skills and training. While staffing and other related implementation impediments are not likely to delay the move back to the USA indefinitely, they will likely hamper efforts to ramp up to full production. There is little understanding of the specific manufacturing skills and training programs TechCo would need to have in place to facilitate the move back to the USA, or of the resources that are available to assist with workforce skill and training issues. If return-to-USA-Production efforts choose sites that do not address the workforce-related impediments, it cannot expect to successfully bring production back. It would likely relocate to sites that don't have the workforce skill and training programs yet in place. The relocation industry has no cohesive understanding of what workforce-related impediments there are and what sites would need to have in place to be seen as highly favorable for production moves back to the USA [7].

Jobs in manufacturing, particularly in the production of durable goods such as machinery, appliances, automobiles, electrics, and precision equipment, typically require skilled employees to operate equipment and maintain a high level of efficiency. In Massachusetts, the manufacturing industry is viewed as critical to maintaining a strong state and national economy. Accordingly, jobs in manufacturing require employees to maintain a high skill level, and employers compensate as such, costing employers significantly more than the average cost of an employee in another industry [8].

4. Case Studies of Successful Implementation

Company A: Small and Medium-Sized Plastic Injection Molding Manufacturer

The pandemic has severely affected many companies, particularly those specializing in plastic injection molding for the automotive and medical industries. After months of turmoil, many companies continued to struggle, mainly because their processes were heavily reliant upon Roku robots and PLC controllers without computer vision capabilities. In other words, their solutions depended on human experiences and not on data analytics, deep learning, or AI technologies. They wanted to find ways to enhance their process and quality management. Fortunately, machine vision systems were also involved. It started with a feasibility study over the deployment of industry camera-based AI computing gateway platforms. New smart manufacturing 4.0 platforms were developed to utilize massive amounts of data collected from the factory floor, analyzing them for the extraction of process knowledge. This changed how forecasting and decision-making were done. A predictive maintenance model displaying the status of production devices and alarm notifications of potential faults and machine downtimes was developed. As well as segregation inspection/decision-making models for defects detection, classification, and root cause tracking, and industrial vision-AI analytics/knowledge graph visualization were adopted to support engineers' decision-making and lift up human rectification performance. These smart manufacturing 4.0 models are baseline guides for other companies producing similar products to develop AI models tailored to their own needs [4].

Company B: A Manufacturing Company Recently Set Up in the US by a Taiwanese Firm

It's a factory established in central Texas with complete lines and production processes. Product quality is strictly controlled in each step, and it has a four-stage quality control process for every product. Smart camera systems are used for surface inspections over the products before cutting and polishing processes. Vision deep learning models are adopted for defects sorting and quality tracing over product defects classification in four processes: laser cutting, ultrasonics cutting, ultrasonic cleaning, and polishing. Each model and camera are responsible for one defect type, and 10 models are deployed to detect curvature errors, positions, surface chips, surface rays, and defects containing contaminants. The smart vision-AI systems are invisible for factory users, but they have gradually changed how quality control is conducted. The topic was raised to share the whole value chain of deploying these smart vision-AI systems. From camera deployment and model training to real-time decision-making deployment, this demonstration is hoped to show the whole picture of smart manufacturing and offer insights into how to handle upcoming challenges in the era of industrial 4.0, especially those new to AI-based smart manufacturing [2].

4.1. Company A: Implementation of AI-Powered Smart Manufacturing Solutions

Company A, a mid-sized manufacturing company in the electronic components sector producing metal casings, underwent an in-depth case study after identifying the need for automation. The pre-smart manufacturing process required workers to manually conduct quality assurance and entry processes with a 10% failure risk. The company invested in AI-powered smart manufacturing solutions that provided real-time product quality monitoring and automatic data entry [4]. The use of machine vision and AI algorithms played a crucial role in detecting component surface defects and converging data from multiple factories to improve AI algorithm accuracy.

Company A's strategy involved closely collaborating with the solution provider, identifying the most impactful production lines to automate, and investing in infrastructure updates such as improving internet coverage and upgrading server infrastructure. The automated production lines showed a 72% reduction in defect risks, improved defect identification from 60% to 90%, and a 90% improvement in manual data entries. Key takeaways from Company A's experience include the importance of top management vision and commitment, thoroughly understanding the production processes being automated, starting with low-risk pilot projects, prioritizing building solid infrastructures, and closely collaborating with AI and smart manufacturing solution providers [2].

4.2. Company B: Overcoming Barriers in Bringing Production Back to the USA

The case of company B is a detailed exploration of the brakes in bringing production back to the USA. It examines all the barriers that were faced and the strategy and actions taken to overcome them. For readers, it offers examples of how to address barriers and can be used to catalyze action within a company or region. The barrier committee offers process, templates, and things that cannot be learned elsewhere. This means that companies address many barriers in the same way. So there is variability in approaches. If Eight Ways to Safari is a quick start guide to production in the USA, Back Jungle is a manual for those who want more details. The best way to deploy it is to keep benchmark sites secret (see Table 1) and let its implementation change questions, then ask other companies what they did. Company B learned this from the region around their main competitor in Mexico.

Company B (names in case studies have been changed) is a growing manufacturer with founders who started the company while in high school. The company's biggest challenge is finding engineers able to conceptualize and solve problems creatively, abundantly, and at varying economic scales. Company B estimates there are less than 100 engineers at the desired level in the country. Nonetheless, Company B has survived with hard engineering ingenuity. The US governing law is intended to protect the intellectual property of its citizens. This becomes a barrier when working with engineers outside the borders of the USA. Multi-national companies often alter or purposely ignore governing laws. It is easy to choose partnerships that appear to be compliant, but when inquiries are made there is nothing to prevent those they partner with from violating laws [3].

5. Best Practices for Implementing AI-Powered Smart Manufacturing Solutions

Implementing AI-powered smart manufacturing solutions may sound complex and risky. However, businesses at various maturity levels can take achievable steps that offer immediate benefits today, paving the way toward advanced deployment down the line. Companies can get started with easily adoptable solutions and prioritize implementation in the most impactful areas of the operation. This means taking simplicity, clarity, and collaboration into account when choosing how to introduce AI to a business's manufacturing operations.

Manufacturers can begin their AI journey with warm-up solutions that require minimal changes to employee workflows, such as predictive maintenance and quality assurance. Firms can demo the effectiveness of AI with discrete pilot projects or proofs of concept. Use exploration projects to build AI maturity and stakeholder buy-in, demonstrating its ability to identify abnormalities and flag production problems without constant human monitoring [4]. These use cases can deliver significant, easy-to-implement value today while serving as a foundation for advanced AI deployment in the future. While less mature businesses may compare solutions strictly on cost, larger manufacturers often look for holistic products and services, including technology implementation [1]. It's necessary to provide a full suite of manufacturing-oriented services that includes technology integration, operational optimization, and, above all, employee training.

5.1. Strategic Planning and Goal Setting

Strategic planning and goal setting are fundamentally important to the successful implementation of any technology. Implementation of AI-powered smart manufacturing solution is no different, except that AI is proprietary technology and that secrecy, even between branches of the same corporation, is expected. Nevertheless, any comprehensive implementation effort must include the following steps: 1. Describe the desired situation in sufficient detail (a wish list or informal narrative may suffice if several SMEs are involved). 2. Describe the current situation in sufficient detail. 3. Analyze and compare the current and desired situation. 4. Identify events, key parameters, or changes that must occur if the desired situation is to be achieved. With that information on hand, one can 5. Construct a conceptual roadmap for a chain of actions that must be taken, events that must happen, or changes that must occur to go from the original desired to the current situation. When constructing a chain of events, the order in which the events occur along that chain must be established with care to maximize payback [9]. Such a conceptual roadmap is likely to be relatively easy to implement. Then, one can 6. Construct a detailed strategic roadmap encompassing that chain of events. The strategic roadmap will lay out how branches of the corporation should nevertheless work together in spite of their expected competitiveness. This section outlines the ideal use case and possible configurations of different AI-assisted smart manufacturing solutions for bringing back production to the USA. Several AI-assisted smart manufacturing scenarios incorporating different options for modifying workforce skills, sensor deployment, data collection, and model construction are described and compared. In addition, they are placed on a timeline outlining when each scenario could take commercially viable shape. The cases are expected to assist technology decision-makers tasked with choosing the most appropriate course of action for implementing AI-assisted smart manufacturing solutions at their companies.

5.2. Collaboration with Stakeholders

The second-best practice for the manufacturing enterprises in the deployment of the AI-powered smart manufacturing solutions is to have the collaboration with the stakeholders, which is a pivotal aspect of the deployment. The collaboration with the stakeholders includes collaboration with the stakeholders representative of the workforce community, education system, internship program managers, and industry/ manufacturing association representatives [4]. To facilitate the seamless integration of the AI-powered smart manufacturing solutions across the US, the collaborative stakeholder eco-systems need to be created. The focus will be on the coordination and facilitation of the collective effort for all the manufacturing enterprises in the country. It is encouraged to foster synergistic partnerships among all the stakeholders within the industry.

To think creatively about and act on the best ways to leverage each stakeholder toward the goal of harmoniously co-funding, co-designing, co-developing, co-deploying, and co-sustaining the emerging AI-powered smart manufacturing ecosystems in the country is important. The Smart Manufacturing Innovation Centers (SMICs) have the networked collaboration with the state and regional smart manufacturing innovation clusters and consortium for continuously engaging and connecting key stakeholders from the local community toward the common goal of smart manufacturing adoption and comprehensive deployment [2].

6. Conclusion and Future Directions

AI-powered smart manufacturing solutions have the potential to bring off-shored manufacturing production back to the USA. The current manufacturing landscape in the USA is described, including challenges and trends in manufacturing. Then results from five successful global manufacturing case studies that implemented AI-powered smart manufacturing solutions are presented. These case studies utilize AI, machine learning, edge computing, and IIoT to obtain an overall view of global manufacturing and improve completely automated production processes. Design for success phase steps and recommendations for US manufacturers to implement AI-powered smart manufacturing solutions are shared. Trends such as rising labor costs and regulations on the environment and safety in China along with tariffs and supply chain management issues are forcing OEMs and Tier 1 suppliers to decide on dual sourcing strategies by manufacturing in both China and Mexico. Intelligent manufacturing solutions are required for manufacturing production with mixed facilities and processed production types, such as fully automated, semi-automated, and human-operated facilities and processes. AI-powered smart manufacturing solutions utilizing AI, machine learning, edge computing, and IIoT technologies connect machines and systems globally and gather and analyze data. AI-powered smart manufacturing solutions bring off-shored manufacturing back to the USA and meet the best practice of design for success for cost-effective implementation of smart manufacturing solutions in the manufacturing domain.

6.1. Summary of Key Findings

In recent years, many large manufacturers have moved production overseas in the pursuit of lower labor costs. However, with the rise of the Internet of things and AI technologies, the manufacturing landscape is changing again. Many small and medium-sized manufacturers (SMMs) in the USA, which were previously "owned" by large multinational companies, face the challenge of bringing production back to the USA or being bought out by foreign interests. However, these SMMs cannot compete with overseas production on an hourly labor cost basis. The need to supplement and replace hourly wage workers with automation solutions presents an opportunity to bring SMM manufacturing back to the USA.

This research proposed a holistic solution termed AIMS+ that resonates with the needs of transforming production facilities from traditional to smart manufacturing, taking advantage of AI technologies in a cost-effective manner. It consists of affordable AI-powered smart manufacturing solutions and business strategy optimization models that return economic feasibility to investments. The feasibility and affordability of the AIMS+ solution were verified via case studies of 3D printing and CNC machining manufacturing. It is anticipated that the AIMS+ solution will significantly lower the cost of smart manufacturing deployment in SMMs, filling the technological gap and promoting the digitalization of the manufacturing sector in the USA. Thus, the AIMS+ solution will help create a new wave of investment in manufacturing in the USA, creating new job opportunities and enabling reshoring, delivering smart manufacturing that will benefit all [4].

6.2. Recommendations for Future Research

AI-Powered Smart Manufacturing Solutions is a promising avenue for future research and inquiry, both for academic researchers and practitioners in the smart manufacturing domain. In the context of small and medium-sized manufacturers (SMMs) seeking affordable solutions and vendors of Artificial Intelligence (AI)-Powered Smart Manufacturing Solutions (SMAs) looking for markets and players, three case studies offer significant lessons and insights. Future inquiry could investigate additional cases, or if possible, conduct follow-on analyses of the Sorted case in its industrial deployment of SMAs. Excessively, it may be interesting to explore the applicability of these findings and lessons to other domains of use being considered by AI firms, such as the agriculture and healthcare sectors [1].

In regard to prospects of further inquiry among the regional SMMs profiled in this investigation, it would be informative to conduct similar monitoring studies as implemented in the boxed case studies, but adapted to local circumstances. Given that substantial industrial deployment timelines are envisioned, studies of this type would likely shed light on longer-term outcomes and impacts. Separated, the exploratory case studies of culturally different smart manufacturing implementations highlight the need for further in-depth follow-on analyses of how affordability and awareness may increase the uptake of affordable AI-driven SMAs in and beyond the US [4].

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