FUJITSU

AI Agents and the Pathway to Evolving Intelligent Manufacturing

Contents

1. Introduction: Why AI Agents Are Essential to the Transformation of Manufacturing Today

The rapid evolution of digital technologies is driving profound change across the manufacturing sector. More than a decade has passed since the concept of Industry 4.0 was introduced, aiming to revolutionize manufacturing through digitalization. Advances in AI, robotics, and industrial IoT (IIoT) have enabled greater optimization of production resources, waste reduction, and the emergence of increasingly connected factories.

Among these technologies, AI has begun to play a pivotal role in areas such as design, production, and quality control–supporting more informed and timely decision-making throughout the manufacturing process. However, the vision of fully autonomous, self-organizing, and adaptive smart factories remains a work in progress. Even the integration of cyber-physical systems (CPS), once seen as a cornerstone of this transformation, has not yet been fully realized on the shop floor.

At the same time, the external landscape is undergoing structural shifts. Unstable supply chains, a declining labor force, and increasing market volatility are pushing manufacturers to adapt faster and more flexibly than ever before. In many cases, conventional automation and CPS frameworks alone are no longer sufficient to address these challenges.

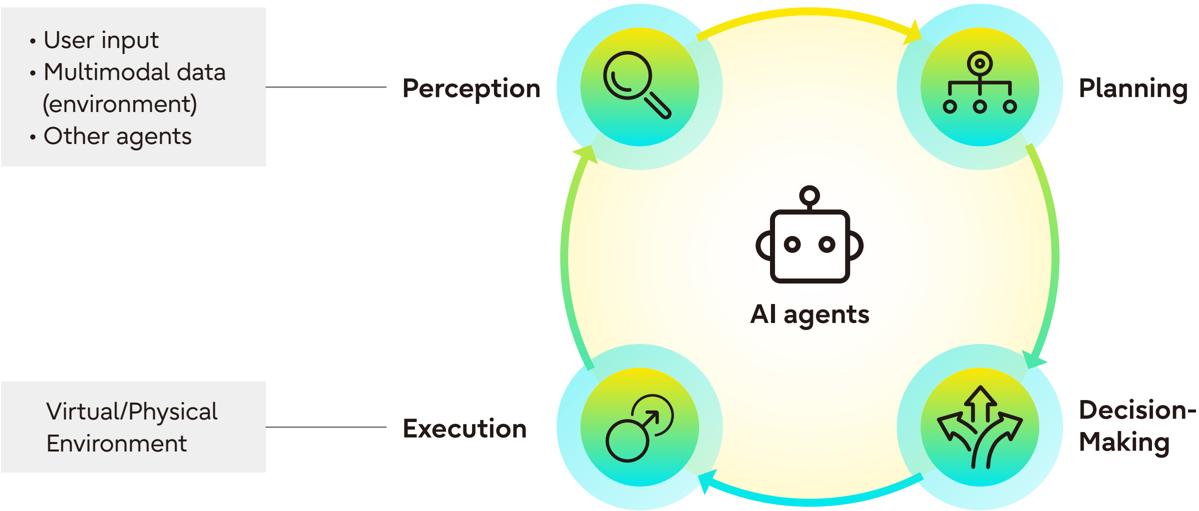
This is where AI agents are gaining attention. With the ability to engage in dialogue, adapt to changing conditions, and act autonomously toward defined goals, offer a new level of agility and creativity to modern manufacturing. By leveraging these intelligent systems, companies can not only boost productivity but also accelerate progress toward greater sustainability and resilience–both critical to future competitiveness.

2. Understanding the Evolution of AI: The Advantages of AI Agents

Traditional AI systems have excelled at performing narrowly defined tasks with high precision, consistency, and explainability. However, their applications have been largely confined to specific domains. In contrast, generative AI represents a major leap forward capable of producing natural language and images, engaging in more fluid human interaction, and offering creative suggestions. Yet, it also introduces new challenges, including factual inaccuracies and difficulties in addressing complex, real-world problems.

Now, a new paradigm is emerging "AI agents". Built on the foundation of generative AI, these next-generation systems possess the ability to understand their environment, plan autonomously, make decisions, and take action to achieve specific goals (See Figure 1). Unlike previous forms of AI, AI agents can manage entire workflows, delivering end-to-end execution capabilities.

Figure 1 Basic structure of a typical cycle of an AI agent



Source: Author

In the manufacturing sector, AI agents hold the potential to dramatically improve productivity, reduce costs, and alleviate labor shortages. Beyond operational efficiency, they can help organizations transcend current limitations by amplifying human creativity and innovation. Their ability to optimize workflows and enhance product development processes makes them a powerful force in shaping the future of manufacturing.

Core Cycle and Components of AI Agents

AI agents operate based on a structured cycle that enables them to make intelligent decisions and act. The typical process includes the following stages:

• Perception
The agent collects data from various sources such as user input, real-world sensors, digital environments, and other agents. This information is then processed to form an accurate understanding of the current context.

• Planning
Based on the observed data, the agent evaluates potential actions, breaks down complex tasks when necessary, and develops a sequence of executable steps to achieve specific goals.

• Decision-Making
Among multiple options or strategies, the agent selects the most effective course of action by weighing trade-offs and determining the best sequence and method for execution.

• Execution
The agent carries out the chosen plan by interacting with internal systems, production equipment, or external services and tools to complete the task.

This cycle is not static; rather, it is built on continuous learning and adaptation. AI agents improve over time by incorporating feedback, analyzing their past decisions, and storing both short-term insights and long-term knowledge.

Furthermore, more advanced use cases involve multi-agent systems, where multiple AI agents work together to automate and optimize end-to-end business processes, such as production lines or supply chain operations.[*1]

Application in the Manufacturing Sector

Incorporating AI agent systems into manufacturing offers a wide range of practical benefits:

- Increased productivity and cost efficiency
- Solutions for labor shortages
- Faster, data-driven decision-making at both operational and strategic levels
- Standardization and automation of tasks to reduce reliance on individual expertise
- Acceleration of innovation in product development and engineering

These AI agents go beyond simple automation. They are strategic enablers that extend organizational capabilities and amplify human creativity and innovation. As such, they are expected to play an increasingly pivotal role in optimizing workflows and driving competitive advantage.

*1 Jianmin Jin (March 2025) "AI agent innovates: Pushing the boundaries of Generative Tech"

3. The Limitations and Evolution of Machine Intelligence (CPS)

Manufacturing operates across both the digital (cyber) and physical environments. In sectors purely within the digital realm–such as financial services–generative AI has already made significant progress and is being widely deployed. Similarly, in manufacturing, the use of AI agents in purely digital use cases is becoming increasingly feasible and accessible.

However, true "intelligent manufacturing" can only be realized when the cyber and physical environments are integrated in real-time and dynamically. To enable such integration, two critical challenges must be addressed.

Challenge 1 **AI Models Capable of Operating in the Physical World Are Still Emerging**

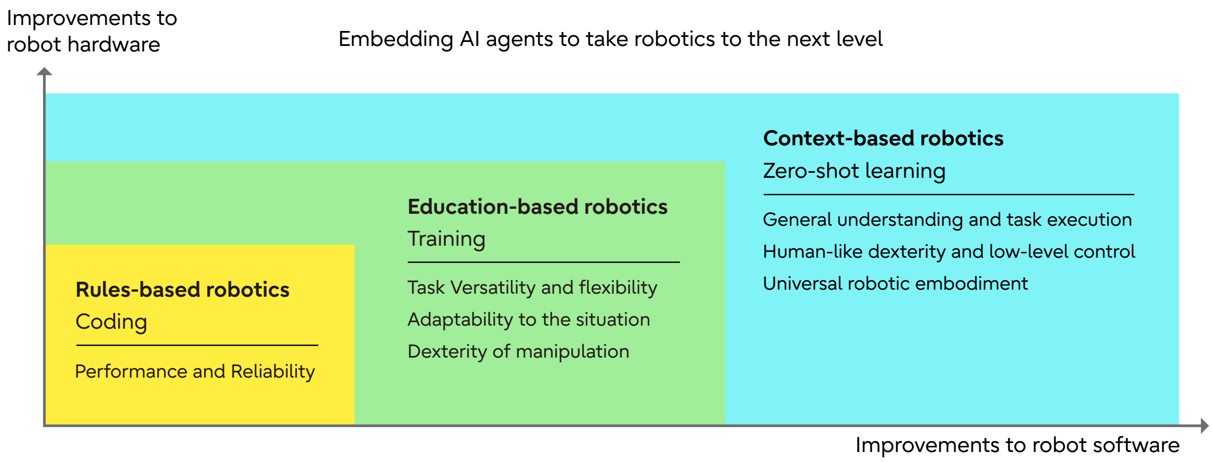
At the core of AI agents lie generative models that must be capable of understanding and responding to both cyber and physical domains at a comparable level. Physical environments are highly variable and ambiguous. Factors such as subtle changes in vibration or temperature, differences in human operation, fluctuations in climate, logistics, and material quality, and even tacit knowledge held by workers all contribute to this complexity.

To date, the development of general-purpose AI models that can handle such real-world variability–especially without extensive task-specific training–is still ongoing.

Challenge 2 **Full Bi-Directional Synchronization in CPS Remains a Barrier**

A Cyber-Physical System (CPS)–which autonomously manages monitoring, prediction, control, and optimization–requires seamless, real-time synchronization between the digital and physical realms. However, the physical world imposes unavoidable temporal and spatial constraints. These constraints create a "gap" that prevents immediate implementation of digitally optimized solutions on the factory floor, posing a significant barrier to fully functioning CPS.

Figure 2 Evolution of embodied AI robot capabilities



Source: Created by the author with reference to WEF (2025) "Frontier Technologies in Industrial Operations: The Rise of Artificial Intelligence Agents"

The World Economic Forum distinguishes between two types of AI agents: virtual AI agents, which operate solely in the digital realm, and embodied AI agents (See Figure 2), which integrate intelligence into physical machines or robots. The latter represents a tangible form of machine intelligence, or CPS in practice. Embodied AI agents are designed to be integrated into physical systems, such as robots, and must be capable of perceiving their environment and interacting with it autonomously. These agents rely on sensors–including cameras, radar, LiDAR, and microphones–to interpret the world, and actuators–such as advanced grippers–to take physical action.

A real-world example can be found at BMW's Spartanburg plant, where humanoid robots equipped with embodied AI are being piloted for assembly preparation tasks.[*2] The practicality of such systems is rapidly increasing, thanks to advancements in robotics foundation models, reinforcement learning, and physical robot engineering.

Ultimately, the full realization of embodied AI agents will come when robots are capable of context-aware behavior–understanding situational nuances and responding accordingly in real time.

*2 BMW group. (2024) "Successful test of humanoid robots at BMW Group Plant Spartanburg"

4. Use Cases and Early Adoption of AI Agents Transforming Manufacturing

Despite the dual nature of manufacturing environments–spanning both digital and physical realms–recent breakthroughs in both software and hardware technologies, such as the generalization of AI models and the adoption of digital twins, are accelerating the evolution of cyber-physical systems (CPS). At the same time, design paradigms that incorporate bi-directional synchronization–such as reconfigurable machines and edge AI deployments tailored to physical constraints–are helping bridge the digital-physical divide. As a result, the development of AI agent use cases in manufacturing is gaining momentum.

Table 1 presents a summary of generative AI agent use cases in manufacturing. At this stage, most practical applications involve virtual AI agents operating within digital domains, as defined by the World Economic Forum. However, emerging semi-automated scenarios–where AI systems collaborate with human operators–are also gaining traction. Looking ahead, we anticipate a growing number of use cases where AI and machine integration give rise to more autonomous, machine-intelligent operations.

Table 1 Examples of generative AI agent use cases in manufacturing

Use Case		Description & Example
1	**Predictive Maintenance**	• Prevent equipment failures by predicting anomalies via sensors and logs
2	**Visual Quality Inspection**	• Detect defects, scratches, or misalignments using AI-powered camera vision
3	**Demand Forecasting**	• Use sales, seasonality, and weather data to forecast product demand
4	**Automated Inventory Management**	• Monitor inventory levels and optimize restocking decisions
5	**Scheduling Optimization**	• Optimize human/machine workloads through AI-based dynamic scheduling
6	**Production process parameters setting**	• AI agents assist in optimizing machine settings, reducing reliance on operator experience and improving efficiency
7	**AGV/AMR Control**	• Route optimization and coordination of autonomous vehicles in factories
8	**Real-time Welding Quality Monitoring**	• Analyze audio, thermal, and video data to detect welding quality issues
9	**Skilled Worker Knowledge Capture**	• Turn expert techniques into digital learning modules using AI
10	**CO_2 Emission Optimization**	• Monitor and reduce carbon emissions from equipment operations

Source: Author

Below are four pioneering use cases of AI agent adoption in the manufacturing sector. Each represents a successful application of cutting-edge innovation to address core business challenges. These early adopters have demonstrated tangible results and now serve as best practices, offering valuable insights and encouragement to the broader industry as it explores AI-driven transformation.

(1) Johnson & Johnson – AI Agents for Drug Discovery Optimization[*3]

Johnson & Johnson has deployed AI agents to optimize complex pharmaceutical processes, such as solvent switching, where molecules are crystallized by replacing one solvent with another. Traditionally, scientists relied on manual, trial-and-error experimentation. Today, AI agents accelerate this process through machine learning and digital twins, significantly improving both cost-efficiency and reliability. At the same time, J&J maintains robust monitoring practices to detect and mitigate risks such as hallucinations or erroneous outputs from AI systems.

(2) KG Steel – Autonomous Control Agent for Steel Manufacturing[*4]

KG Steel, a South Korean steel producer, faced two pressing issues: high liquefied natural gas (LNG) energy costs and inconsistencies in product quality due to a generational skills gap in the workforce. To address these challenges, the company implemented a predictive control optimization model that feeds AI agent outputs directly into the furnace control system–enabling partial automation of furnace operations. The initiative led to a 2% reduction in LNG consumption and a measurable improvement in product quality and consistency.

(3) Siemens Electronics Works Amberg (EWA) – AI-Driven Autonomous Quality Control[*5]

At EWA, Siemens strives to exceed a First Pass Yield (FPY) rate of 95% and reduce Defects Per Million Connections (DPMC) to below 10. Yet with up to 3,800 quality parameters per printed circuit board, traditional quality control has proven highly complex. In response, EWA developed a patented autonomous AI agent for quality management. This agent supports solder paste printer settings, shortens process cycle times, and continuously optimizes process parameters–ultimately enabling automated, self-adjusting operations.

(4) Cosentino – AI Agents for Customer Service Automation[*6]

Cosentino, a Spanish manufacturer of architectural and design surface materials, has integrated AI agents into its customer service operations as part of a "digital workforce." These agents are rigorously trained and operate under strict protocols to ensure accuracy. As a result, the AI agents now handle order processing tasks that previously required three to four full-time employees, allowing human staff to focus on higher-priority responsibilities. Cosentino also applies AI agents successfully in credit management and maintains system performance through ongoing monitoring and retraining.

*3 J&J (October 10, 2024) "6 ways Johnson & Johnson is using AI to help advance healthcare"
Belle Lin (January 6, 2025) "How Are Companies Using AI Agents? Here's a Look at Five Early Users of the Bots"
*4 WEF (January 2025) "Frontier Technologies in Industrial Operations: The Rise of Artificial Intelligence Agents"
*5 Belle Lin (January 6, 2025) "How Are Companies Using AI Agents? Here's a Look at Five Early Users of the Bots"
*6 Ryan Stevens (November 5, 2024) "Cosentino leverages AI to optimize global operations and drive efficiency"

5. Three Strategic Recommendations for Manufacturing Leaders Shaping the Future

AI agent technologies are evolving rapidly, reshaping not only operational efficiency but also redefining organizational roles, business models, and competitive landscapes in manufacturing.

This journey of transformation holds the promise of an autonomous, intelligent manufacturing future co-created with AI agents.

Many industry leaders have already embarked on this path. Here are three strategic recommendations to help you take the next step with confidence.

(1) Redefine Business Goals and Evolve AI Transformation Strategies for the Intelligent Era

With AI advancing at an unprecedented pace, companies now have unparalleled visibility into operations, enabling impact measurement, interaction analysis, and optimized decision-making.

This shift calls for a reassessment of your company's core business objectives, ensuring they align with the opportunities of the intelligent era.

Moving beyond isolated AI initiatives, it's critical to develop a comprehensive "AI Agent Transformation Strategy" at the enterprise level–complete with clear KPIs and a well-defined execution roadmap that places AI agents at the heart of your business evolution.

(2) Build Bridges to Close the Gap Between Digital and Physical Realities

AI agents are increasingly capable of autonomous decision-making and adaptation in dynamic manufacturing environments. Yet, significant gaps remain between digital advancements and physical constraints–due to physics, safety requirements, design complexities, and differing innovation paces.

Closing this gap requires a two-fold approach:

On the digital side: Leverage generative AI for synthetic data, enhance digital twins to better mimic human-machine interaction, and deploy AI at the edge with multimodal, distributed CPS architectures.

On the physical side: Embrace modular design principles and systematically standardize, codify, and digitize on-site processes and knowledge.

Together, these efforts form the essential "bridge" to fully unlock AI agents' potential on the factory floor.

(3) Cultivate an Organizational Culture That Co-Creates with AI

As AI agents integrate deeper, human roles evolve from operators to AI collaborators– empowered to make informed decisions alongside intelligent systems. Team structures will shift from fixed groups to agile, often virtual, task forces.

To thrive, every team member must develop the skills and mindset to work in harmony with AI agents. Leaders need to master governance of both human talent and potentially thousands of AI agents, while nurturing each employee's growth alongside the company's transformation.

Building a resilient, flexible organizational culture that values human creativity, and adaptability is essential to fully realize the promise of AI-augmented manufacturing.

The future of manufacturing will be co-created by humans and AI agents alike. And the ones leading this transformation will be those closest to the frontline, with a clear vision and the courage to act. Let's step forward together into this new era.

About the author

Dr. Jianmin Jin

2020-　Fujitsu Ltd., Chief Digital Economist

1998-2020　Fujitsu Research Institute, Senior Fellow

Dr. Jin's research mainly focuses on global economic, digital innovation/ digital transformation, and Dr. Jin has published books such as "Towards the create of a Japanese version of Silicon Valley", etc.

Recent writings: the following Fujitsu Insight Paper, etc.

- Creating a Virtuous Cycle of Transformation and Trust: A Future Strategy Powered by AI and Net Positive Thinking (2025)
- AI agent innovates: Pushing the boundaries of Generative Tech (2025)
- Designing the Next Generation of Intelligent Manufacturing with Generative AI (2025)
- Innovative Banking with Generative AI: Exploring Use Cases and Value Creation (2024)
- Leveraging the LLM: Strategy from Model Selection to Optimization–Insight for top management (2024)
- Generative AI: Use Cases as the Pathway to Value Creation (2024)

The author would like to thank Daisuke Suzuki, Koichi Shirahata, Naomi Hadatsuki, Takashi Shinden, Hiroko Meguro, Yukiko Sato and Mitsuo Tsukihara for their invaluable advice and unwavering support in creating this paper.

June, 2025 v1.0