Executive Perspectives

17

Unlocking the Value Potential of AI

Manufacturing

June 2025

Introduction

We meet often with CEOs to discuss AI—-a topic that is both captivating *and* rapidly changing. After working with over 1,000 clients in the past year, we are **sharing our most recent learning in a new series designed to help CEOs navigate AI**. With AI at an inflection point, the focus in 2025 is on turning AI's potential into *real* profit via widespread implementation of AI agents.

In this edition, we discuss the future of manufacturing and the role AI will play in turbocharging growth. We address key questions on the minds of manufacturing leaders:

- What will the future of industrial operations look like?
- Where is the value at stake in an AI transformation? What will be the role of virtual AI and physical AI?
- What enablers need to be put in place to realize value at scale?

This document is a guide for CEOs and manufacturing leaders to cut through the hype around AI in manufacturing and understand what creates value now and in the future.

In this BCG Executive Perspective, we articulate the vision and value of the future of manufacturing with AI

Executive summary | Unlocking the value potential of AI in manufacturing

The time to act on AI in manufacturing is now

The manufacturing environment is becoming more challenging given increased cost competitiveness and growing labor shortages, necessitating the shift toward more productive and sustainable operations

Acceleration of computing power, the narrowing of the simulation to reality gap, and the evolution of AI are rapidly expanding the application potential of AI in manufacturing

There is an opportunity to drive a 30%+ productivity increase in industrial operations through an end-to-end AI transformation

AI will reshape manufacturing factories to be more self-controlled

Virtual AI and physical AI enable a step-change from traditional manual, labor-intensive operations to highly efficient, self-controlling production

Virtual AI automates digital workflows such as setpoint optimization, production planning, and defect detection in quality control, while reducing downstream defects by improving upstream process design

Physical AI enables physical systems, e.g., robots, to perceive and interact with their environment, enabling new tasks such as material handling of flexible parts, complex assembly, and bin picking of unknown parts

Executing successfully requires a transformational mindset

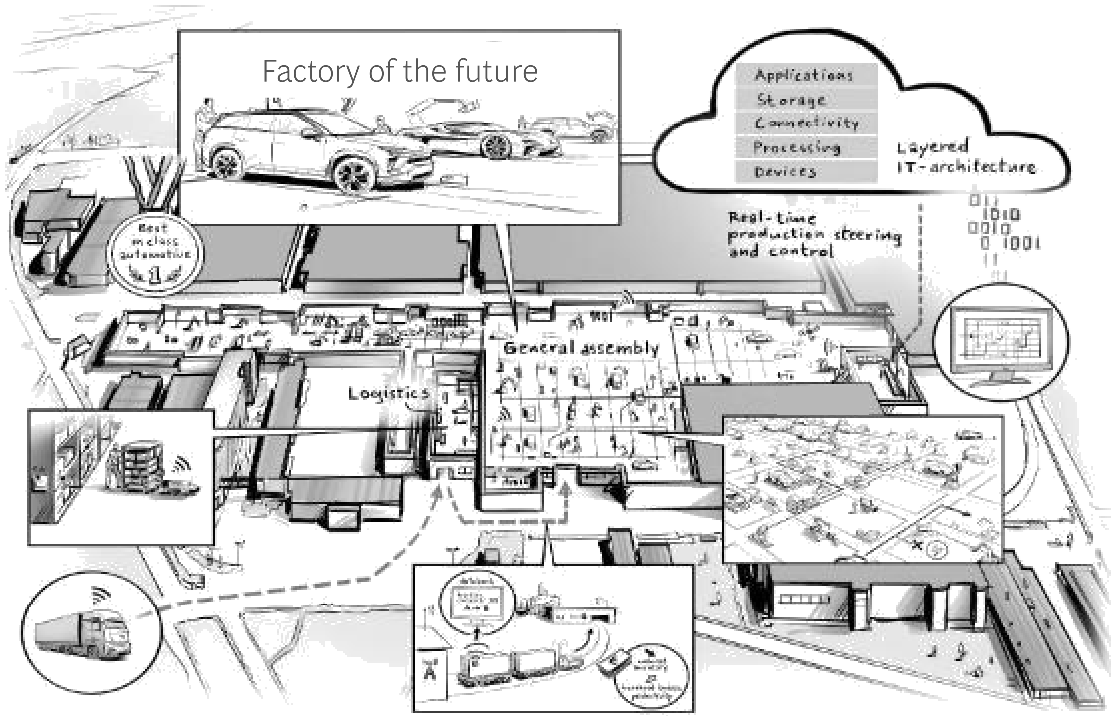
Unlocking the full value of AI requires a transformative effort, where success depends on AI algorithms (10%), technology infrastructure such as IT/OT architecture (20%), and people foundations (70%)

People foundations include the definition of the right governance, understanding future capability requirements, linked upskilling strategies, and change management driven by leadership activation and team engagement

To get started, we recommend identifying your pain points, defining target state and roadmap, piloting and scaling prioritized use cases while establishing the right foundations

The factory of the future will be AI-enabled to become largely autonomous – two foundations are critical to succeed

Optimization dimensions | Virtual AI | Physical AI | ... more *(not in focus in this publication)*



Foundations | Technology (IT/OT infrastructure) | People (governance and competencies)

The factory of the future will have...

70% "Lights-out" operations

App store of AI agents with seamless integration

Central "nervous system" monitoring processes 24/7

BCG is partnering with leading global manufacturers to boost manufacturing competitiveness using AI

The factory of the future has 3 characteristics …

1 **Autonomous**

Advancing factory automation with closed-loop management systems

2 **Scalable**

Replicating global operational excellence across all locations

3 **Learning**

Rapid self-evolution and continuous improvement

… to unlock significant value

Productive **Flexible** **Sustainable**

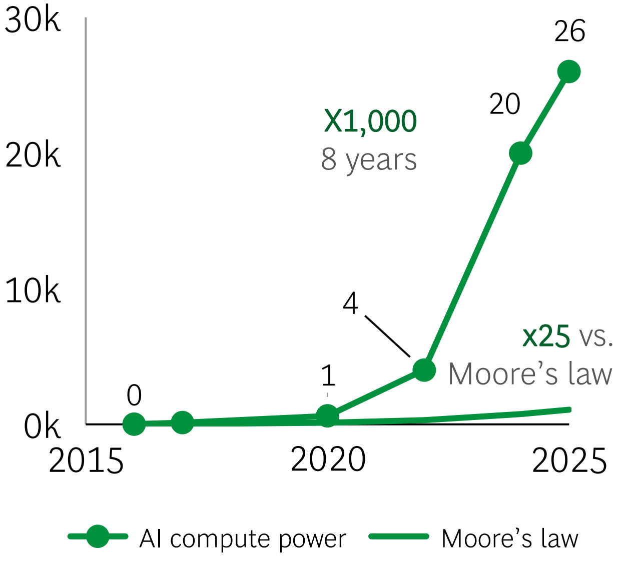
Scan to watch a video on a BCG reference case

FOXCONN

Why now? Three foundational technologies are redefining what's possible

1 Acceleration of computing power

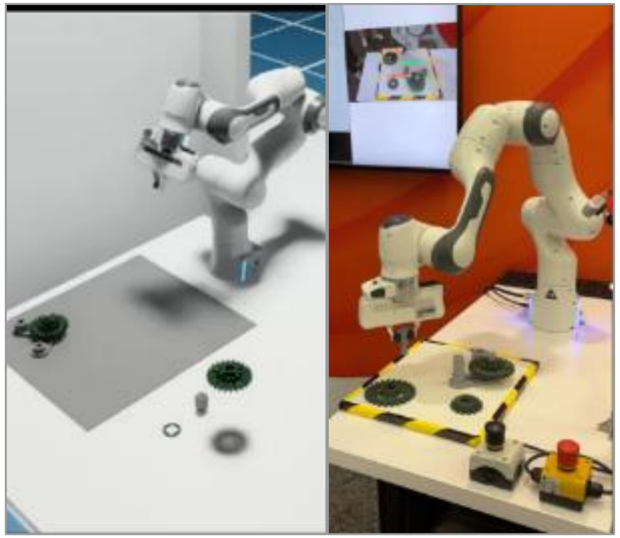
AI compute power (TFLOPS)



Massive increases in compute power enable next-level analytics and simulation at lower costs

2 Narrowing of simulation to reality gap

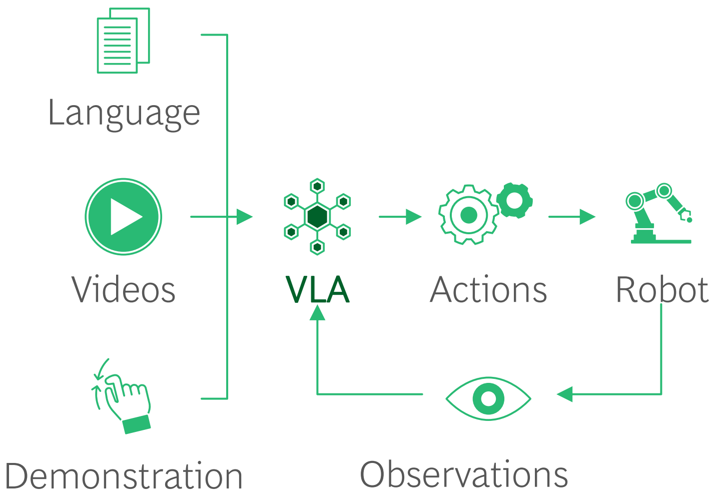
Simulation / Real world



Allows for accurate training of AI models for wide varieties of applications, even when real data is scarce

3 Development of foundation models

Vision-language action model (VLA)



Enables AI systems that learn from surroundings to perform a wide range of tasks, even in unfamiliar environments

AI empowers factories with autonomous capabilities, utilizing both virtual and physical AI

Virtual AI

Enable software-based applications to autonomously achieve a defined goal in the factory

Capabilities

- **Perceives**, collects, and processes data
- **Plans** possible actions and optimizes toward a digital goal
- **Acts** by leveraging internal or external tools/systems

Key benefits

Supports workers in decision making

Enables self-controlling systems

Physical AI

Automate systems to autonomously interact with the physical environment and perform complex tasks to achieve a defined goal

Capabilities

- **Observes** and **understands** physical/spatial environment
- **Plans** movement workflow based on physical constraints
- **Interacts** with environment and **manipulates** objects

Key benefits

Expands automation scope

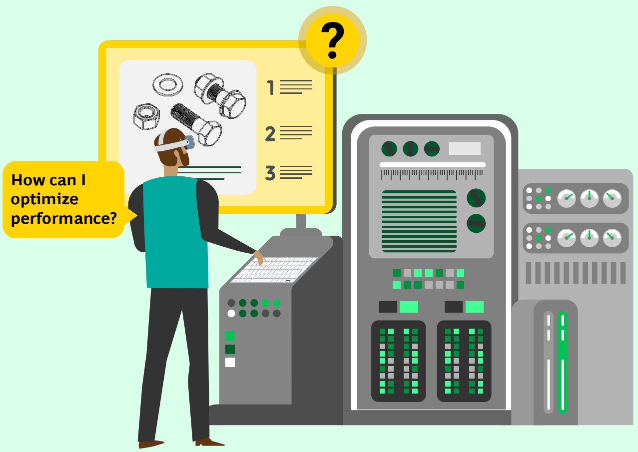
Simplifies robotic implementation

Virtual AI | Applications will move from operator support to autonomy

Current AI horizon | Next AI horizons

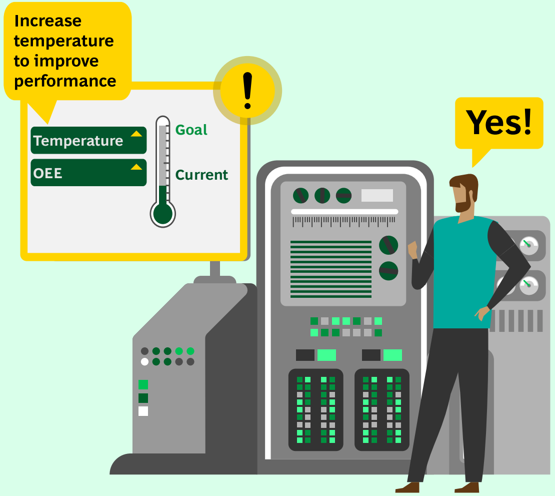
Assistant systems

Assistant behaves as a thought partner with large knowledge base



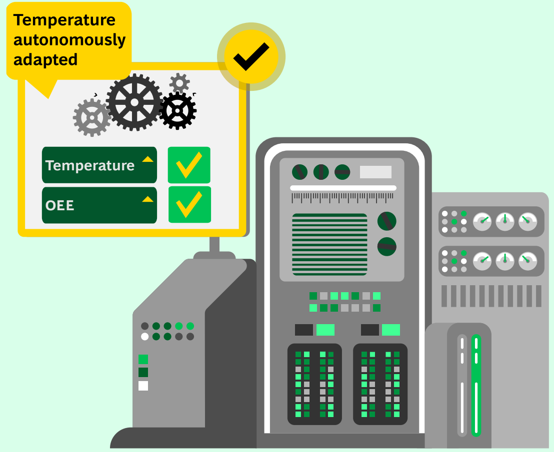
Recommendation systems

Recommendation engine provides engineers with optimal decision



Autonomous systems

Systems autonomously monitor performance and implement decisions



Use case example

Assistant systems:
- Operator chatbot
- Maintenance support agent with SOP[1] integration
- Production system advisor

Recommendation systems:
- Maintenance technician recommendation
- Machine setpoint advisor
- Predictive quality control and defect detection
- Scheduling optimizer

Autonomous systems:
- Self-controlling machine setpoint
- Self-optimizing production planning
- AGV[2] fleet steering agent
- Meta-agent for factory control

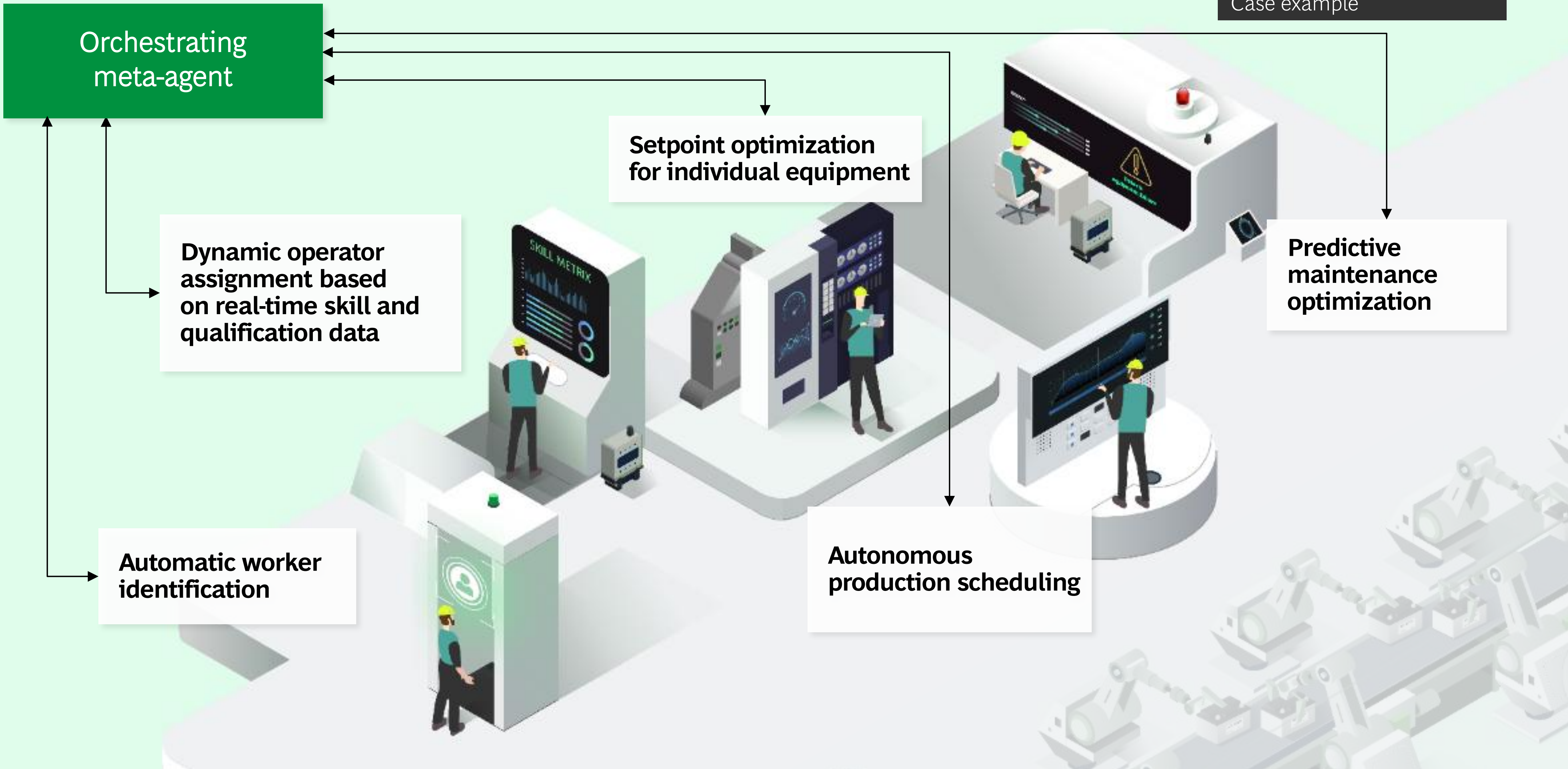
Human-led

AI-led

1. SOP: standard operating procedure 2. AGV: automated guided vehicle

Virtual AI | Meta-agent will orchestrate autonomous operations

Case example



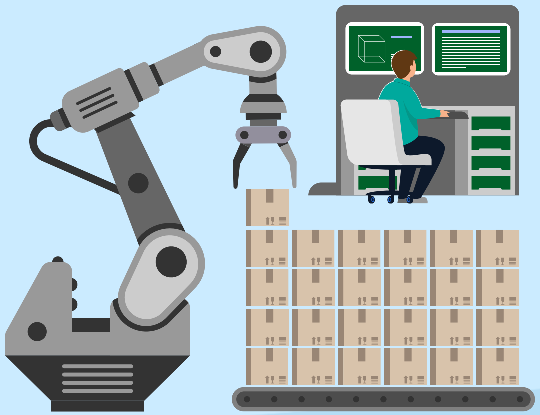
Physical AI | Applications will expand automation scope and simplify implementation

Current AI horizon

Next AI horizons

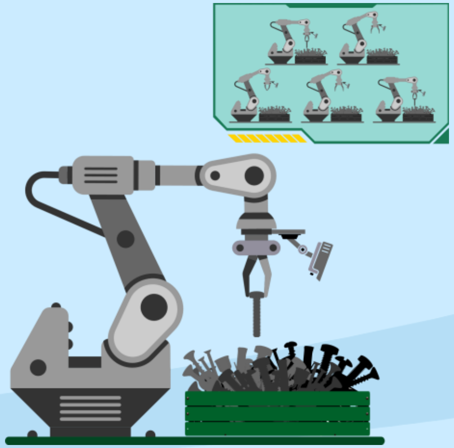
Rule-based robotics

Robot moves exactly as human programmer codes



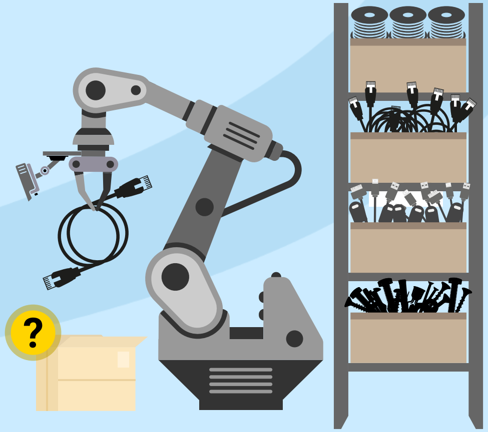
Training-based robotics

Robot learns complex tasks through training



Context-based robotics

Robot autonomously understands context through zero-shot learning



Use case example

Rule-based robotics:
- Rule-based automation for fixed workflows with specific parts
- Part-specific coding and finetuning by robotic engineers

Training-based robotics:
- Automation of complex tasks with self-adaptation to variations
- Robot skill training with RL[1] in reality or simulation

Context-based robotics:
- Fully adaptive system handling any complex and unpredictable task
- Zero-shot learning for application without training

Impl. effort

Automation scope

1. RL: reinforcement learning

Physical AI | Self-adapting robotic system increased scope of automation and reduced engineering effort

Case example

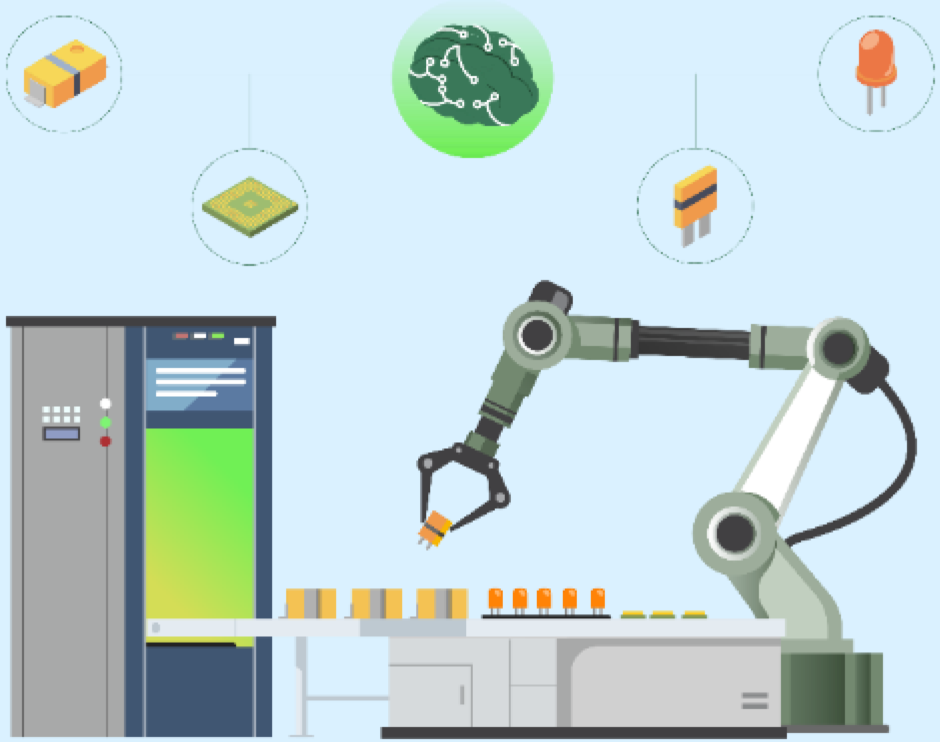
Self-adapting robotic system:

Automating manual insertion of components in PCB[1]

Leading electronics company aimed to automate through-hole technology (THT) manual insertion process.

With AI training environments becoming virtual, **training efforts significantly reduced** and parallel processing was enabled. The BCG engineering team built an automated THT mounting application capable of **accurately perceiving component shapes in real time**.

This ensured accurate insertion, reduced manual labor, and shortened retooling when transitioning between product variants.



-50% automation engineering time

-70% engineering staff hours for implementation

1. PCB: printed circuit board

Physical AI | Humanoid applications in manufacturing are being explored in multiple domains

Context-based robotics can take any robotic form factor, including the human form

Humanoid robots are general-purpose robots that can execute any human-like activity

Humanoids are expected to have potential in multiple domains …

Hazardous work

- Emergency response (e.g., fire fighting, nuclear plant operations)
- Security
- Search and rescue

Home/Personal care

- Elder care
- Home care
- Nursing
- Customer service (e.g., cooking)

… but impact in manufacturing is currently limited

Humanoid use cases currently niche

Humanoids will have some use cases in manufacturing; however, they are currently niche applications, and some flexibility or dexterity like navigating stairs is not needed in manufacturing

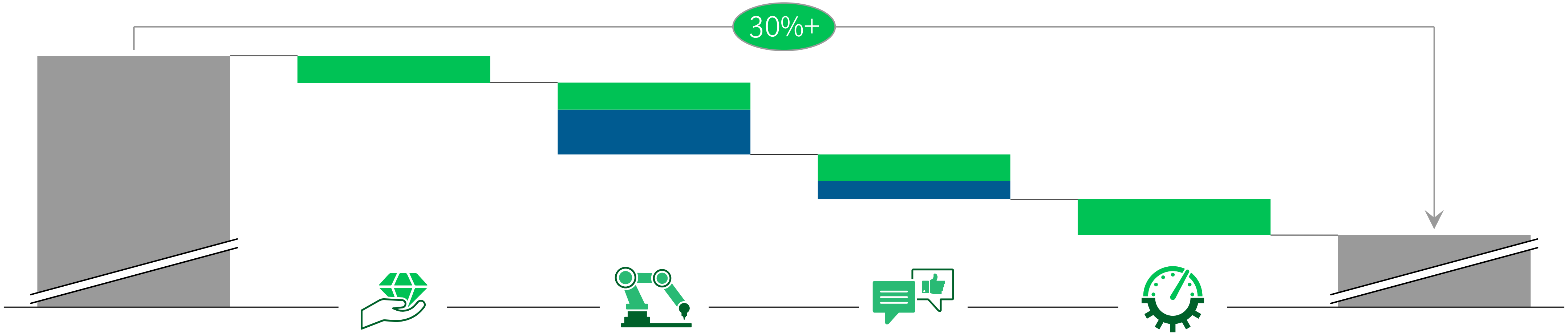
Single-purpose robots outperform generalists

General-purpose robots are currently less efficient than task-optimized robots and aren't significantly cheaper to produce or train

E.g., it is more efficient/cheaper to use one logistics robot and one assembly robot working together than one generalist robot capable of both tasks

AI can potentially unlock 30%+ productivity gains in manufacturing

Manufacturing impact through end-to-end virtual and physical AI implementation



Reduced quality costs
~30% non-quality cost reduction

Higher production efficiency
~50% direct labor task automation

Fewer mfg. engineers
~25% indirect labor task automation

Improved equipment effectiveness
~25% increased machine performance

Key Virtual AI | Physical AI

Source: BCG experience

Case example | E2E transformation achieved 21% labor productivity increase

BCG case example: industrial goods

Four key elements for factory transformation

	#	Key solutions	Impact
Virtual AI	1	Predictive analytics and machine self-control in machining	**+15pp** OEE by proactively identifying downtime risks and maximizing machine utilization
Virtual AI	2	Simulation and synthetic data for predictive quality control	**-32%** non-quality costs via automated real-time defect detection and predictive insights enabled by digital twins
Physical AI	3	End-to-end material flow automation	**-61%** material-handling direct labor headcount, freeing up employees for higher-value work
Physical AI	4	Robotic automation for complex part handling and assembly	**-40%** direct labor headcount while creating safer work conditions and opportunities for specialized upskilling

Value realization on the shop floor

31% Labor productivity impact achieved

€190M Total yearly saving impact

Note: Based on initial indicators during project/pilot
Source: BCG

Successful AI transformations require a high focus on foundations

10%

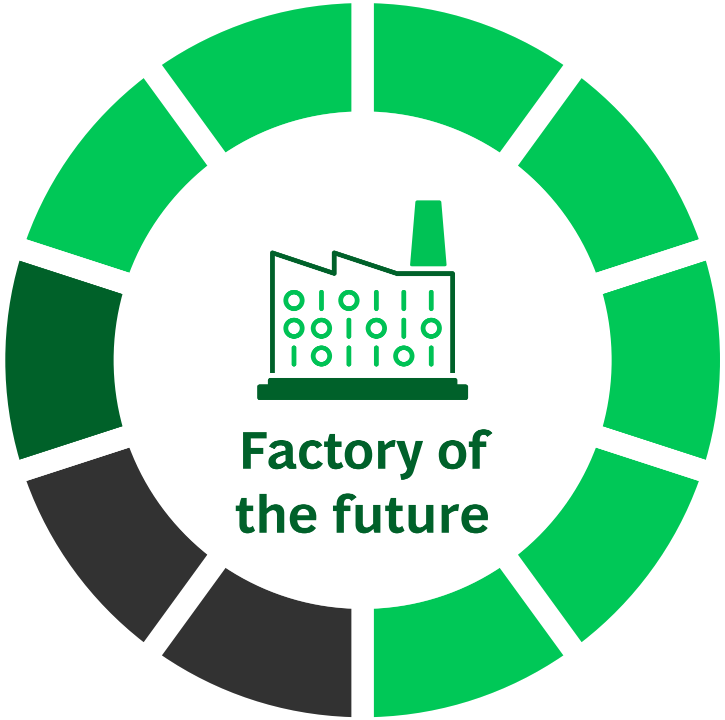
Optimization / AI algorithms

- Integrate AI into digital and physical factory systems to enable end-to-end automation
- Ensure integration follows effective structure and lean processes

20%

Technology foundation

- Deploy future IT/OT system architecture
- Build unified data platform as single source



70%

People foundation

- Governance and steering: define vision, establish efficient and clear team structure for AI oversight, and ensure alignment with evolving AI regulations and ethics
- Talent and capabilities: develop AI expertise through upskilling and cross-hiring
- Structure and roles: set up lean structures with AI-led execution and human oversight
- Target culture and purpose: foster transparent communication and cultural adaptation

Technology foundation | Tech stacks will evolve to support AI

Typical current tech stack

Smart business layer
- Dashboards and self-service analytics
- Decision-support systems
- Software tools and HMI

Analytics layer
- Existing AI solutions
- Orchestration and CI/CD
- Development environment
- ML ops

Data layer
- Repository and storage
- Data model and taxonomy
- Data versioning tools
- Ingestion and distribution

Core transaction layer
- ERP
- MES
- WMS
- SCADA
- Others

Infrastructure
- On-premise
- Cloud
- Hybrid

AI-enabled tech stack

Virtual AI applications / Physical AI
- Virtual assistant systems
- Autonomous agents
- Recommendation engines
- Robotic applications

AI layer
- Existing AI solutions
- Improved orchestration and CI/CD
- Development environment
- ML, LLM, and VLM ops
- AI monitoring and safeguarding tools
- Simulation capabilities
- Model garden

Data layer
- Exchange, repository, storage
- Data versioning tools
- Integrated factory model
- Data model and taxonomy
- Ingestion and distribution

Core transaction layer
- ERP
- MES
- WMS
- SCADA
- Others

Infrastructure
- On-premise (TPU/GPU)
- Cloud
- Hybrid

Layer interfaces/capabilities upgraded and impacted by AI

Key takeaways

- Virtual AI assistant systems and agents are **transforming operator/worker experiences**
- **Entry barriers** to complex applications and robotic deployment are reduced

- Simulation capabilities and synthetic data generation enable physical AI training
- Emphasis is on **versatile analytics layer** (off-the-shelf models, hybrid AI solutions, etc.)

- Integrated factory model combines process and factory digital twins
- AI tools **accelerate data consistency** and taxonomy reconciliation into **UNS (unified namespace)**

- Interaction with core systems is abstracted via co-pilots and/or AI agents (wrappers)
- AI tools and interfaces serve as easy-access interfaces to legacy landscape

- Cloud resources **minimize vendor-dependencies** in a fast-changing market
- Edge computing is critical for physical AI to minimize latency and inference time

People foundation | Four pillars are important to ensure sustainable impact from AI

Governance and steering

- Define **AI-first vision with (de)central governance rules and guardrails** to ensure responsible AI use
- Establish **clear roles and responsibilities** through the RACI[1] framework to ensure reliable leadership
- **Monitor evolving AI regulations** (e.g., EU AI Act) to ensure compliance across applications
- **Align with industry standards** (e.g., implement best practices for AI ethics, risk mitigation, and data security)
- Maintain up-to-date technical documentation to provide **transparency for internal governance**

Talent and capabilities

- Develop **training plan** (e.g., new role-play training leveraging KPIs/alerts)
- **Activate leaders and champions** on the shop floor (e.g., via train-the-trainer initiatives)
- **Enhance AI engineering skills** by focusing on model deployment and automation in production environments
- Define **end-to-end AI workflows** across departments to ensure consistent execution and accountability
- Implement structured operational processes with regular team meetings to **monitor implementation**

Structure and roles

- Establish a **flatter hierarchy with a leaner structure**
- **Share business and tech accountability** and define the role of the center clearly
- Deploy **AI agents to execute and lead decisions**, with **humans providing oversight** and managing exceptions
- Establish **cross-functional ownership** for AI processes to support iterative development and feedback loops
- Integrate **AI initiatives into daily factory operations** to drive long-term value and operational continuity

Target culture and purpose

- Develop **AI-first mindset** with shared purpose, adaptability, and trust in human-agent collaboration
- Emphasize **change management and communication** as people are key enablers of AI transformation
- Implement **new communication and collaboration tools**
- Refine **KPIs to reflect productivity gains and** implement **user-level monitoring**
- Ensure **(short-term) incentives drive adoption** and cross-functional/team/regional collaboration

1. RAC: responsible, accountable, consulted, and informed stakeholders

People foundation | AI will free up humans and require new skills

Illustrative

	Direct manufacturing	Production scheduling	Machine maintenance	Quality control	Material handling and logistics
Today	Operators manually assemble products and operate machines, requiring precision and continuous concentration Human error leads to **variations in product quality**	Planners manually adjust production schedules based on orders, machine availability, and worker shifts – **scheduling is reactive and based on historical data**	**Machines are serviced after they break down or at regular intervals**, whether they need it or not Engineers rely on visual checks or logs to assess machine health; failures are often unexpected	Workers visually inspect products for defects, which is **slow, subjective, and prone to human fatigue** Random sampling means some defective units may slip through	Workers manually prepare, sort, and transport materials with forklifts or carts Work requires human coordination; **inefficiencies, accidents, and misplacements** happen
Future *With virtual and physical AI*	Operator monitors machine performance across various production areas such as assembly, at the same time **supervising self-optimizing** machine setpoints	**AI-driven scheduling systems** continuously analyze demand, machine conditions, and workforce availability in real time and **automatically adjust** as necessary	AI-driven sensors analyze vibrations, temperature, pressure, and other parameters **to predict failures before they happen**, and repairs are scheduled proactively to eliminate downtime	AI-powered cameras **scan each unit in real time, consistently detecting defects** humans may miss AI also **predicts defects** before they occur by monitoring machine data	**AI-driven autonomous mobile robots handle materials end-to-end**, ensuring the right parts are delivered on time Work shifts from manual labor to supervising a robotic fleet

Workforce reduction

Reskilling

New hires

Three steps unlock value of AI in manufacturing …

Support along the way

1

Diagnostics and target state

Run a **diagnostic to determine current value leakages**. Set **target state ambition,** build business case and roadmap

2

Pilot and launch

Run pilots to **establish blueprint** across select use cases. **Refine workflows**

3

Scaling across plants

Iterate, rewire, and **scale prioritized use cases** across plants, to **drive organization-wide adoption**

… and five factors ensure success throughout an AI transformation

Transformation needs to be led from the top with management inspiring by example

Full focus should be on creating value with use cases that have productivity gains via AI

Scalability needs to be considered from day 1 by setting up enablers

Tech and people foundations need to be a key focus to support AI

Employees of all levels should be involved and upskilled to drive excitement and AI literacy across organization

Source: BCG

BCG experts | Key contacts for AI in manufacturing

Daniel Küpper
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