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# Harnessing the AI Revolution in Industrial Operations: A Guidebook

WHITE PAPER

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Images: Getty Images

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# Foreword

**Daniel Küpper**
Managing Director and Senior Partner, Global (Co-)Lead BCG Manufacturing and Supply Chain, Boston Consulting Group

**Kyriakos Triantafyllidis**
Head of Growth and Strategy, Centre for Advanced Manufacturing and Supply Chains, World Economic Forum

Although continuous improvements in production efficiency have historically been a cornerstone for maintaining the competitiveness of global enterprises, conventional means of enhancing productivity in manufacturing are becoming increasingly exhausted. On the other hand, the growing significance of data and advanced manufacturing technologies, such as artificial intelligence (AI), offers fresh avenues to improve not only production efficiency and flexibility, but also to drive sustainability and empower the workforce.

Many manufacturers have already integrated AI into their operations. However, the majority struggle to achieve their AI-related targets. This shortfall predominantly arises from inadequate organizational and technological foundations, which are essential for scaling AI solutions throughout production networks. At the same time, AI's evolution continues unabated, with innovations such as generative AI emerging on a regular basis.

In 2022, the World Economic Forum – in collaboration with Boston Consulting Group (BCG), the Centre for the Fourth Industrial Revolution in Türkiye and TÜV SÜD – launched a global initiative on AI-Powered Industrial Operations. The goal is to support manufacturers on their AI journey, ensuring they harness AI's full potential in manufacturing and supply chains.

This white paper delves into the initiative's findings over the past year, derived from consultations with a community of leading manufacturers, technology innovators and academic experts. It offers insights into the current state of AI adoption in industrial operations and sheds light on recent advancements in the field. The centrepiece of the paper is a guidebook intended to help manufacturing companies continuously capture the full value of AI as the technology evolves. The guidebook highlights the crucial considerations and steps of the AI journey – from defining the overarching objectives of AI in operations to identifying, building and scaling the relevant applications and required foundations to ensure they stay at the forefront of AI innovations.

We trust that this white paper and guidebook significantly contribute to efforts to deploy AI in industrial operations by helping manufacturers navigate their AI transformation to reach the next frontiers of productivity, agility, sustainability and workforce engagement.

# Executive summary

## This report presents a guidebook for harnessing the AI revolution in industrial operations.

Manufacturing companies operate in an increasingly complex environment marked by heightened economic pressures, the sustainability imperative, the need for resilience and escalating capability challenges coupled with a talent shortage.[1] Advanced manufacturing technologies, including AI, have a pivotal role in enabling companies to navigate these challenges and tap into new value streams. According to a global BCG study on AI in industrial operations from 2023,[2] these technologies enable productivity enhancements of more than 20%. Recognizing the opportunity, about 90% of companies across various industries are looking to incorporate AI into their operations. However, this contrasts with the fact that only one in six of these companies have met their AI-related objectives to date. This shortfall is primarily attributed to a lack of foundational prerequisites both from an organizational and a technological perspective.

Although most industrial companies struggle to realize the full potential of AI, the technology continues to evolve.[3] Innovations such as generative AI present additional opportunities to reinvent certain operational processes and to transform how employees work in plants. For example, through generative AI it is possible to provide employees with question-and-answer platforms or give detailed work instructions for specific maintenance incidents, including visualizations, the required spare parts and other essential information. These capabilities remain largely untapped but can be successfully adopted with the right implementation approach.

To support manufacturing companies on their AI journey, the World Economic Forum's Centre for Advanced Manufacturing and Supply Chains – in collaboration with BCG and a community of operations and technology executives as well as academic experts – has co-developed a guidebook for harnessing the AI revolution in industrial operations. This guidebook draws upon insights gained by exploring the untapped potential of AI in industrial operations and the variety of AI applications that manufacturers currently deploy.

The guidebook consists of five sections, with the first three representing the different stages of a manufacturing company's AI journey and the latter two describing the building blocks needed for a successful AI implementation and scaling:

- **Paving the way for success from AI in industrial operations:** Highlighting the importance of articulating an organization's long-term AI objectives and transformation principles as a starting point on the AI journey.

- **Mastering the AI journey across production networks:** Describing a step-by-step approach from the status quo assessment to the design, engineering, implementation and scaling of value-adding AI applications and required foundations.

- **Staying at the forefront of AI innovations:** Explaining the importance of conducting periodic AI reviews to continuously identify and integrate AI innovations and related opportunities as they emerge.

- **Value-adding AI applications for industrial operations:** Pinpointing AI-based applications that address inefficiencies and operational opportunities to achieve intended improvements and outcomes.

- **Foundations for AI implementation in industrial operations at scale:** Defining the AI-related organizational and technological foundations to enable implementation at scale and long-lasting success.

Recognizing that an AI journey is not a one-time effort, the guidebook helps manufacturers to continually adapt to the rapid advancements and innovations of AI applications in industrial operations.

Moving forward, the World Economic Forum's Centre for Advanced Manufacturing and Supply Chains will continue to work closely with manufacturing stakeholders across industries to support the long-term journey towards AI-powered industrial operations by incubating innovative AI pilots and shedding light on the most common quality gaps observed when implementing AI systems in an industrial context.

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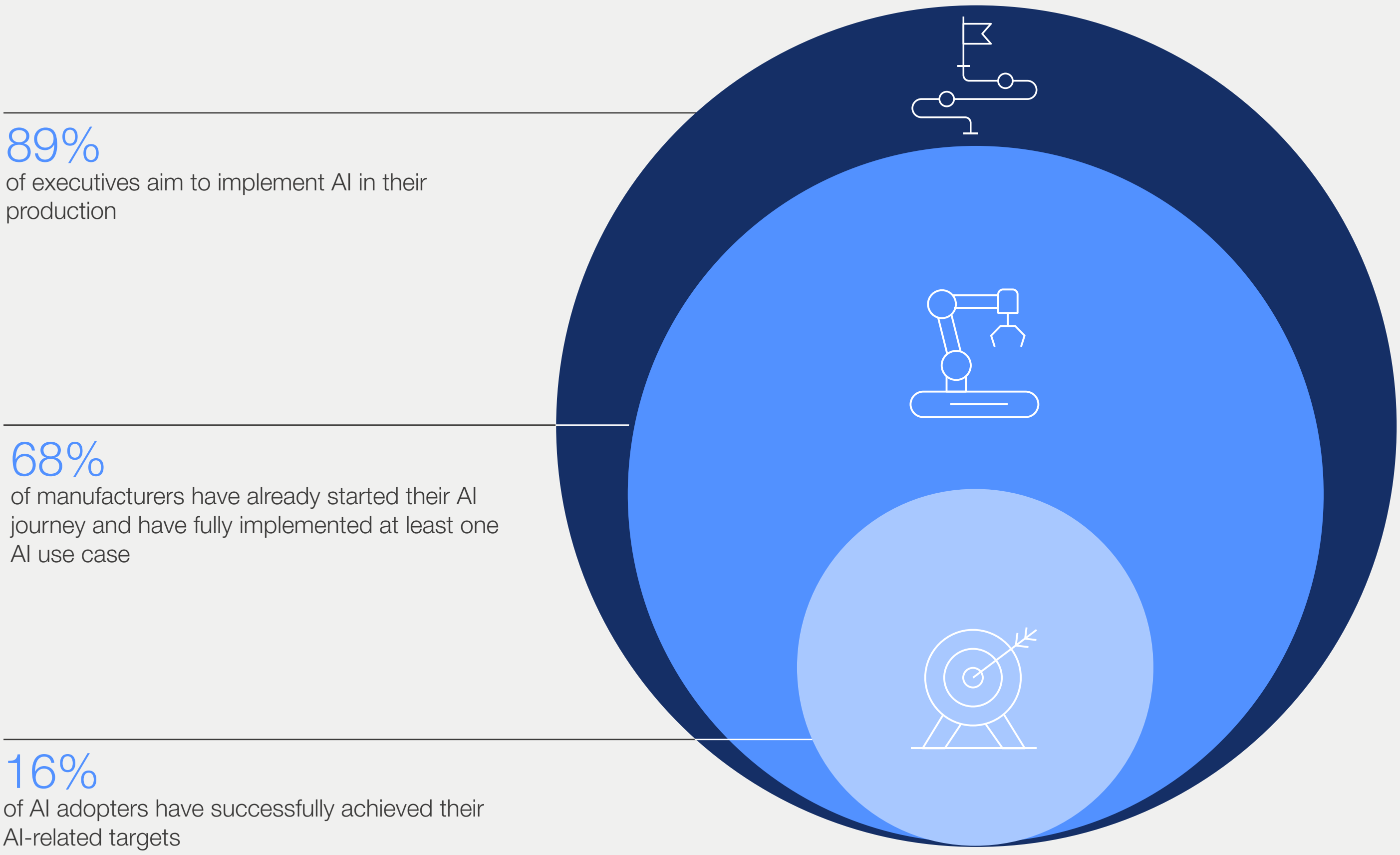
# AI's potential in industrial operations

Most manufacturers are still unable to successfully implement and scale AI, yet the evolution of AI regularly reveals new innovations and opportunities.

The operating environment for manufacturing companies has grown increasingly complex, characterized by economic pressure, the sustainability imperative, the necessity for agile operations and capability challenges exacerbated by talent shortages.[4] Advanced manufacturing technologies such as AI can help manufacturers address this complexity and unlock the next wave of value through improvements in productivity, enhanced production flexibility and workforce support, among other benefits. Seeing the opportunities, leading manufacturers are exploring how to implement these technologies.

The adoption of AI technologies such as machine learning (ML) and deep learning (DL) has facilitated a shift from traditional deterministic and rule-based systems to probabilistic and goal-oriented automation. Applications, such as demand forecasting or computer vision-based quality control, are becoming increasingly prevalent in manufacturing operations.[5] According to a recent BCG study involving more than 1,800 manufacturing executives worldwide, 89% of respondents across industries regard AI as essential. A notable 68% of manufacturers have already started their AI journey, fully implementing at least one AI use case in production. However, a mere one-sixth (16%) of these companies have already achieved their AI-related targets (Figure 1). Nearly all executives (98%) cited the primary reasons for this shortfall as inadequate organizational foundations – such as a lack of digital skills and capabilities – and a lagging technology base in areas such as data processing.[6]

FIGURE 1: **Current state of AI adoption in industrial operations**




Source: BCG, Global Survey on AI in Industrial Operations 2023[7]

These findings confirm that activities and efforts are underway within industrial operations to adopt AI. Yet many companies have become stuck in the piloting phase and are unable to scale their solutions and capture the full value of AI across production networks and value chains. At the same time, the evolution of AI and related technologies continues – an example is the introduction of 4nm chips featuring an astounding 80 trillion transistors, which can deliver up to 6.7 times greater performance than the previous chip generation.[8] In this context, recent advancements in generative AI present exciting opportunities, promising to unlock potentials that extend well beyond the use of ChatGPT in the manufacturing environment. Based on consultations with AI experts, the enabled applications can be categorized into three main types: assistance systems, recommendation systems and autonomous systems (Figure 2).

FIGURE 2: **Three main types of generative AI applications in manufacturing**

### Assistance systems

Generative AI applications that are similar to a ChatGPT tool in the manufacturing environment, enhancing the efficiency of manual activities such as programming or machine maintenance

- **Workforce questions and answers:** Allowing individuals to pose questions – e.g. on a bill of materials (BOM) – and receive instantaneous answers tailored to the enquirer's background
- **Machine and programmable logic controller (PLC) programming co-pilot:** Facilitating the programming of machines by drafting code or code blocks or reviewing existing code – e.g. to automate a manual process
- **Process report and documentation tool:** Enabling the automated generation of documents such as quality reports after a major product defect, or maintenance documentation following an equipment breakdown and repair

### Recommendation systems

Generative AI applications making recommendations, thereby helping operators pinpoint the most optimal solutions for specific tasks

- **Maintenance co-pilot:** Extending the ML- or DL-based predictive maintenance approach with proposed responses. The co-pilot recognizes incidents or alerts from the predictive systems – e.g. the need to swap out a particular machine component – and augments them with step-by-step maintenance instructions, accompanied by images and visualizations, or even guidance on the required spare parts and tools
- **Root cause suggestion tool:** Advising how to sustainably solve root causes identified by failure analyses, such as by eliminating recurring issues in an assembly process or machine incidents
- **Quality and yield improvement tool:** Suggesting, for example, the ideal components for setpoint optimization via ML in order to increase yield

### Autonomous systems

Generative AI applications with capabilities for self-control and adaptability to new environments

- **Synthetic training data generation:** Enabling the synthetic creation of training data with unprecedented speed and accuracy – e.g. a computer vision-based quality control process must be trained on a significant number of samples of good and defective parts to ensure high reliability. These samples are typically collected during the ramp-up phase of a new product, which initially results in diminished system performance and necessitates manual intervention. In contrast, using synthetically generated training data can markedly accelerate this process
- **Robotics transformers:** Allowing for the automation of less-repetitive material handling procedures and swift adoption of robotics to unfamiliar environments without the need for individual retraining and data labelling

Source: World Economic Forum and BCG analysis

The above examples provide an initial glimpse into the transformative applications and impact of generative AI within the manufacturing environment – from increased labour efficiency and heightened productivity to cost reductions, as well as augmented production flexibility.

Across multiple industries, companies need to process thousands of shipments daily. SAP has used generative AI to process goods receipts for these shipments. Delivery details from unstructured paper documents are automatically extracted and populated into the transportation management system, which reduces the effort of employees, who otherwise have to read and enter the delivery note data manually. Implementing this solution at an automotive company made it possible to reduce the receipt processing time by 55–70%.[9]

As of today, many of the generative AI applications described are still in the research stage or have been implemented only in pilot projects. Yet, considering the rapid technological advancements and the growing interest generative AI is triggering within the manufacturing community, it is expected that these solutions will soon be present in industrial operations at scale. They will likely coexist with the more conventional ML- or DL-based AI applications, which are better suited for analytical tasks such as anomaly detection, production analytics, setpoint optimization and forecasting.

AI-related advanced manufacturing technologies and developments will continue to emerge, accompanied by new and even more diverse requirements – often at a faster pace than most companies can adopt them. One example of these new innovations is quantum computing technology, which, like AI, will also have a disruptive impact on industrial operations and on AI itself.

Such developments create a pressing need for approaches that enable more rapid implementation and scaling of innovations. To embrace these AI developments in a target-oriented way, a holistic strategy for AI adoption is needed, encompassing a clear vision of AI tailored to the individual industrial context, the suitable value-adding applications and the foundational prerequisites.

Recognizing the untapped potential of AI, as well as the associated challenges,[10] and considering the pace of technological progress in this field, the World Economic Forum, in collaboration with BCG, consulted with a community of industrial operations and technology executives, as well as experts from academia, to co-develop a guidebook for harnessing the AI revolution in industrial operations. The guidebook presented in this paper outlines a comprehensive approach for organizations to successfully navigate their AI transformation journey in a fast-developing environment.

BOX 1. **How different AI technologies relate to each other**

- **Machine Learning (ML):** ML is a distinct subset of AI that allows systems to automatically learn and improve from experience – data – without being explicitly programmed on specific rules; for example, to predict values, calculate probabilities, identify cluster/groups and identify correlations.
- **Deep Learning (DL):** DL is a subset of ML, based on neural networks, and is suited to making deep connections within the data based on large amounts of data and performing multiple calculations for its features for each layer.
- **Generative AI (GenAI):** As a subset of DL, generative AI produces high-quality new content in multiple formats such as text, images, code, videos and music.

Source: IBM[11]

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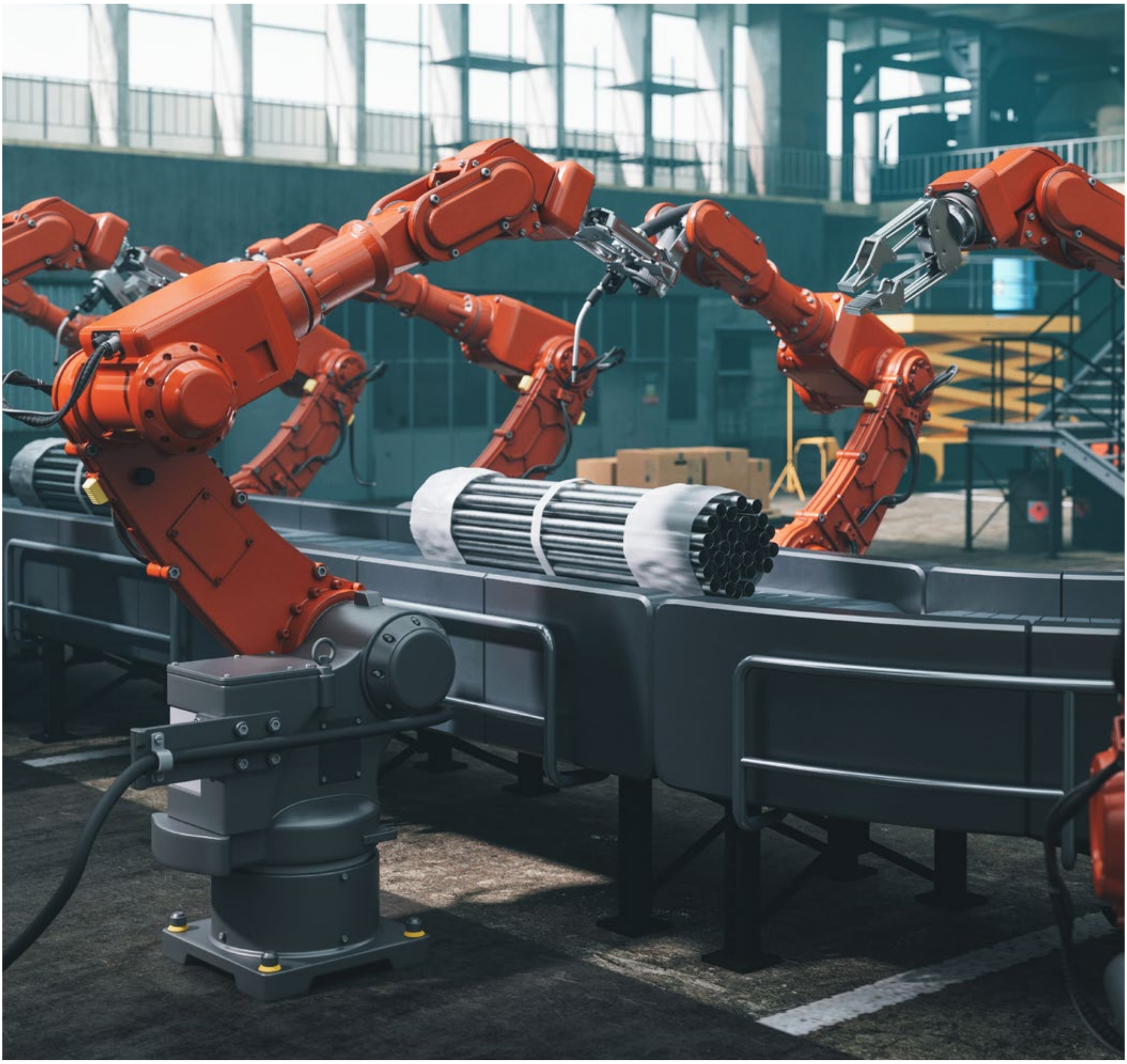
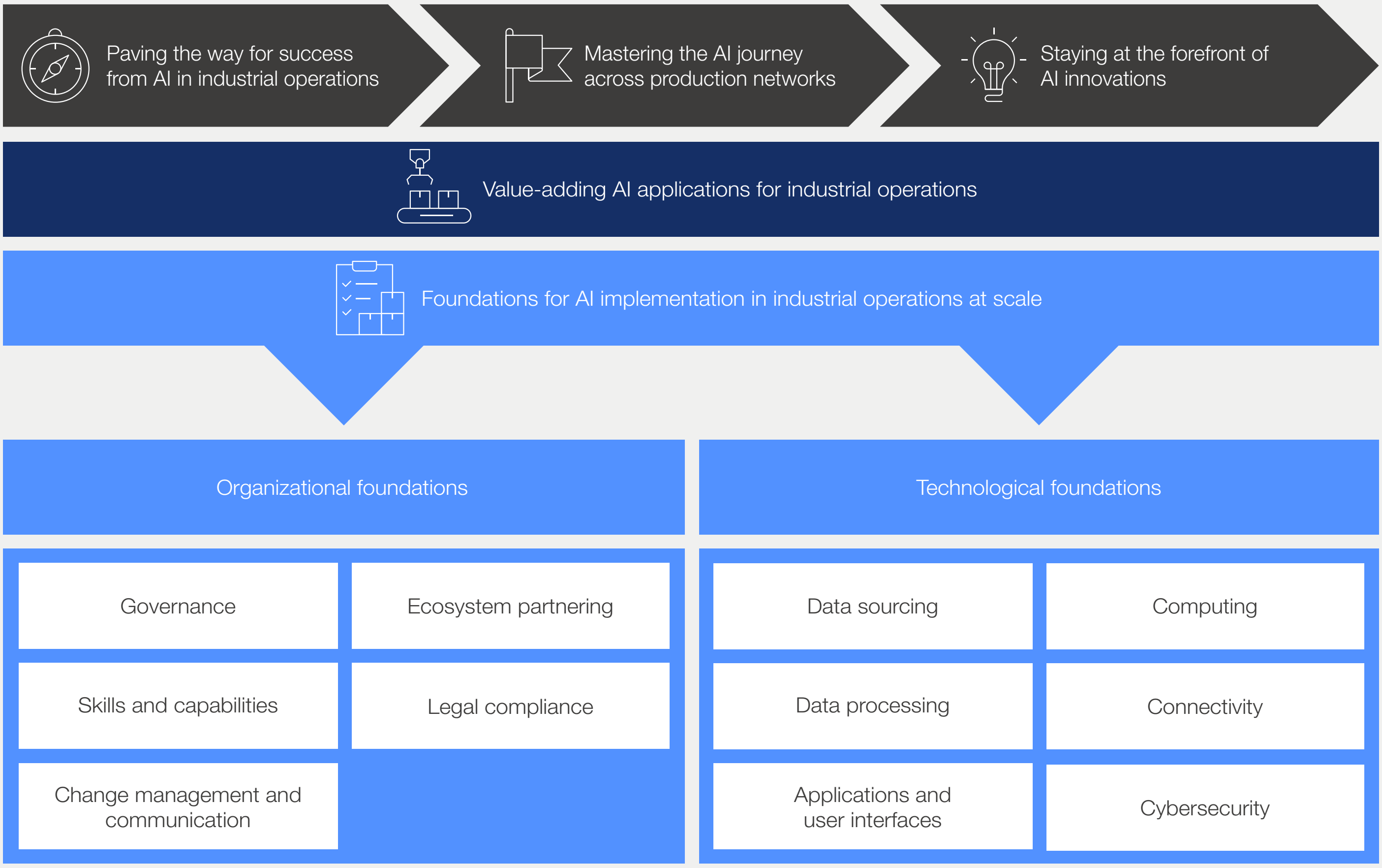
# Harnessing the AI revolution in industrial operations: a guidebook

A new guidebook to systematically approach and master the AI journey at scale in industrial operations.



The implementation and, particularly, the successful scaling of AI in industrial operations is often hindered by a wide range of challenges. The guidebook presented in this white paper aims to help manufacturers alleviate these challenges by shedding light on best-practice approaches adopted by leading manufacturers and technology experts on their AI journey (Figure 3).

FIGURE 3: **Harnessing the AI revolution in industrial operations: a guidebook**




Source: World Economic Forum in collaboration with BCG

The guidebook has five sections. The first three sections represent the overarching stages of a company's AI journey:

– **Paving the way for success from AI in industrial operations:** Highlighting the importance of articulating an organization's long-term AI objectives and transformation principles as a starting point on the AI journey.

– **Mastering the AI journey across production networks:** Describing a step-by-step approach from the status quo assessment to the design, engineering, implementation and scaling of value-adding AI applications and required foundations.

– **Staying at the forefront of AI innovations:** Explaining the importance of conducting periodic AI reviews to continuously identify and integrate AI innovations and related opportunities as they emerge.

The final two sections comprise the building blocks needed for a successful AI implementation and scaling:

– **Value-adding AI applications for industrial operations:** Pinpointing AI-based applications that address inefficiencies and operational opportunities to achieve intended improvements and outcomes.

– **Foundations for AI implementation in industrial operations at scale:** Defining the AI-related organizational and technology foundations to achieve implementation at scale and long-lasting success.

While a white paper published in December 2022[12] considered the various value-adding AI applications, this paper focuses on the three stages of an AI journey and on the final stage, the AI-related organizational and technological foundations.

## 2.1 Paving the way for success from AI in industrial operations

A successful AI journey starts by developing a clear understanding of the reasons for adopting AI and defining the vision and objectives of the organization. Whether the vision is to increase efficiency and agility, augment the capability of the workforce or reduce emissions, grasping the “why” streamlines the entire industrial transformation. Developing an AI strategy that allows the company to achieve its targets aids in pinpointing the right AI applications, facilitates transparent communication with all stakeholders and prevents misguided investment decisions.

In this context, aligning on the organization’s transformation principles can ensure that all subsequent actions are directed towards the initial vision and objectives. While such principles vary depending on company-specific considerations, some consistently come up as being a vital starting point for success. An important principle to start with is the adoption of a value-driven approach with a consistent end-to-end perspective, to define the AI target picture and subsequently identify the related applications. To ensure a smooth rollout across plants, it is also essential to think about the scalability of applications from the outset. Additionally, to drive buy-in at various levels, taking a pilot approach with rapid implementation of use cases can demonstrate impact and value. This test-and-learn approach can also highlight any adjustments needed for a successful rollout. Finally, keeping the organizational and technological foundations in mind along the entire journey is essential to enable the use of AI at scale.

When Siemens introduced an AI-based predictive quality solution to increase surface-mount technology (SMT) production, a value-driven approach with a clearly defined problem statement (describing the as-is) and target definition (aligning the to-be) was followed. Having an aligned view on the status quo and the objectives upfront helped over the course of the entire implementation, achieving a substantial lead time reduction and quality improvement, as well as reducing energy consumption as a consequence of an enhanced testing process. After the initial impact and with a higher level of process understanding, Siemens has scaled the solution to additional plants and used the deployed infrastructure on other products and machines to maximize the value generated.

## 2.2 Mastering the AI journey across production networks

Unlocking the full potential of AI applications requires going beyond initial pilots and deploying solutions across the entire manufacturing network. Based on the insights collected from senior executives in operations and technology experts, here are five key steps for identifying and implementing value-adding AI applications at scale and setting up their associated foundational enablers (Figure 4):

- **Diagnosis: analysing the status quo and identifying gaps and opportunities** – including identifying and quantifying inefficiencies and potential opportunities, understanding the required skills and capabilities and corresponding capability mismatches and assessing the required technology prerequisites and the existing needs for action based on the current technology infrastructure.

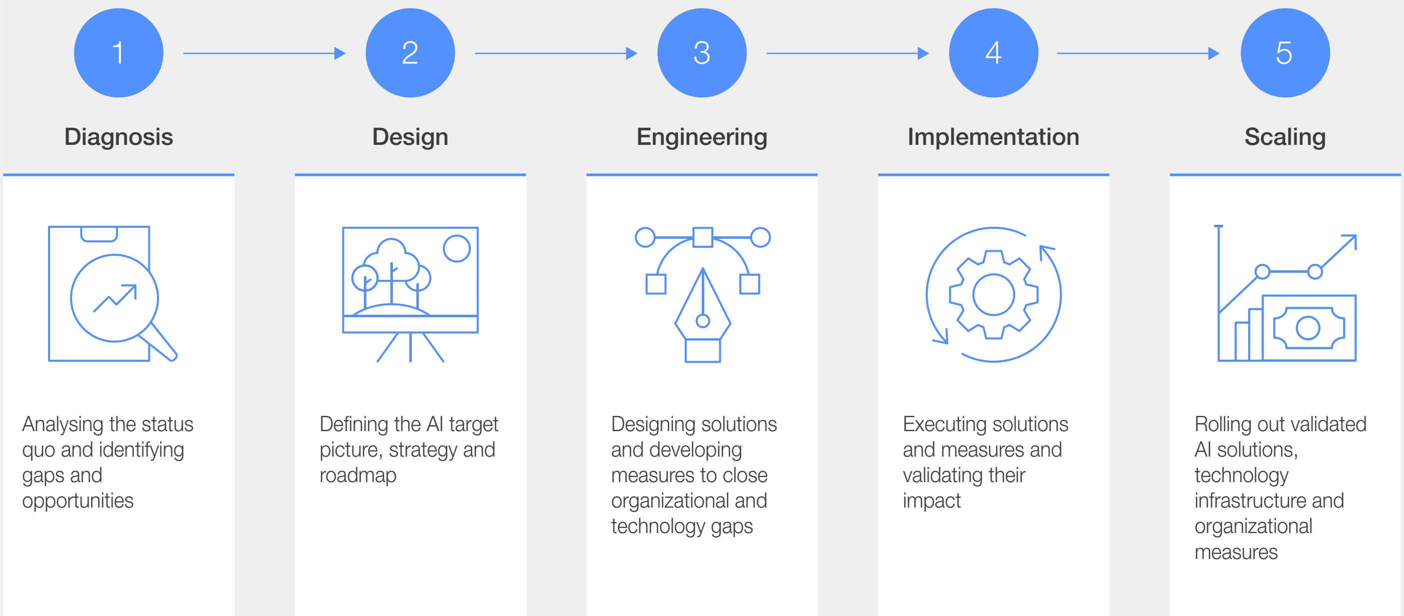
- **Design: defining the AI target picture, strategy and roadmap** – including determining the most beneficial AI applications based on impact and required investment, deciding on a make-or-buy strategy and defining the AI-related governance, capability-building strategy and change management and communication approach, as well as making design choices along the technology infrastructure dimensions.

- **Engineering: designing solutions and developing measures to close organizational and technology gaps** – including assessing potential solution vendors, engineering technical solutions and proof of concepts and developing a capability-building programme and technology infrastructure solutions.

- **Implementation: executing solutions and measures and validating their impact** – including implementing and validating proofs of concept for AI solutions and related technology infrastructure in pilot areas and launching and testing the capability-building programme, governance and change management approach in pilot plants.

- **Scaling: rolling out validated AI solutions, technology infrastructure and organizational measures** – including monitoring of progress according to the roadmap across the entire production network.

FIGURE 4: **Step-by-step approach for mastering the AI journey across production networks**




Source: World Economic Forum in collaboration with BCG

## 2.3 Staying at the forefront of AI innovations

The rapid advancements in AI indicate that implementing and scaling AI will require more than a one-time effort. Recent breakthroughs – for example, innovations in generative AI – and the new potential they unlock in manufacturing and supply chains highlight the importance of viewing AI implementation as an ongoing journey. Industrial organizations that fail to do so risk missing out on, or belatedly adopting, new developments.

Defining and implementing a systematic approach for periodic AI reviews and maturity checks lays the foundation for staying at the forefront of AI innovations, promoting long-lasting results and impact. By regularly verifying and updating the AI target picture and aligning it with the business strategy and organizational priorities, manufacturers can continuously tap into fresh opportunities and capture the full potential of AI. This also requires equipping the organization with the right mechanisms and resources to scout for the latest AI innovations and opportunities affecting manufacturing and supply chains. This process can be enabled by, for instance, an organizational structure that includes a central team dedicated to supporting the entire AI journey across the production network. One of the mandates of this team would be to regularly review new developments in AI – for example, by joining relevant platforms or attending corresponding events and technology conventions.

## 2.4 Foundations for AI implementation in industrial operations at scale

Strong organizational and technological foundations are essential for implementing and scaling AI applications across a production network and achieving the goals of enhanced productivity, sustainability, flexibility and workforce support. This section provides an overview of these foundations and associated considerations derived from the leading organizations that contributed to this guidebook's development.

### Organizational foundations

Drawing from their experiences with AI implementation, experts emphasized that, while mechanisms to identify the most value-adding applications are widely available, the most significant challenges often pertain to the organizational set-up itself. Within this context, five key AI-related dimensions were derived from the consultations conducted: governance; skills and capabilities; change management and communication; ecosystem partnering; and legal compliance.

#### Governance

Successful AI implementation and scaling require clear governance that is relevant to the efforts being undertaken. This governance builds the foundation through an adequate organizational structure, clearly defined roles and responsibilities, required processes and appropriate incentives and key performance indicators (KPIs):

– **Organizational structure:** Tailoring the organizational structure to the company's specific needs to support the AI journey. A common practice is to use a hybrid approach: a central digital unit coordinates the implementation and rollout of AI applications across plants, while individual plants spearhead the actual implementation and are fully accountable for their progress.

– **Roles and responsibilities:** Using the RACI logic – which defines responsible, accountable, consulted and informed stakeholders for tasks and activities related to the AI journey – to support ownership and ensure execution in accordance with the roadmap. In addition to considering the multiple roles needed, a common practice in industrial operations is to designate initiative leads from specific plants to oversee AI applications and their cross-network implementation. These leads are supported by an initiative coordinator from a central team.

– **Operational processes:** Establishing clearly defined processes, such as regular team meetings to monitor the implementation progress or machine learning operations (MLOps) procedures. In addition, depending on the AI applications being implemented, it is essential to review and adjust operational processes and standard operating procedures to accommodate the new requirements and workflows.

- **Incentives and KPIs:** Defining targets based on the overarching AI objectives and roadmap, and deriving suitable KPIs to monitor the AI implementation process and its impact. In addition, it has proven beneficial to establish incentives for all stakeholders to drive ownership at all levels. Because AI initiatives tend to run concurrently with routine operations, employees often need to allocate dedicated time to engaging in AI tasks and achieving defined targets.

### Skills and capabilities

Having access to the right AI-related skills and capabilities is instrumental for a successful AI journey and its sustainable scaling and impact. Key capabilities and proficiencies that have emerged are:

- **Data analysis:** Executing data analysis, interpretation, visualization and design of training data for AI models and model validation.
- **Data architecture:** Defining AI-related data needs and the required data architecture to facilitate data availability.
- **Data engineering:** Realizing data availability, usability and quality by building the requisite AI-related information technology (IT) and operational technology (OT), a data platform and data pipelines to automate high-volume and real-time data delivery.
- **Data sciences:** Automating complex data analysis processes through the design and development of statistical algorithms and models, such as those based on ML.
- **Software engineering and development:** Developing front-end and back-end software for AI applications and AI-based tools.
- **ML engineering:** Bringing ML models to production, which includes testing and optimizing models, as well as establishing the MLOps infrastructure.
- **Automation engineering:** Automating shopfloor activities by implementing and connecting industrial control hardware and using simulation tools for rapid prototyping of automation systems.

Given the nature of AI, its applications also require development and implementation by cross-functional teams with diverse expertise at the convergence of IT, OT, data and AI technologies. In addition to the primary technology-related capabilities needed to develop, implement and operate AI applications in an industrial setting, a set of soft skills has also proven to be instrumental in the transformation. These include eagerness to learn, problem-solving capabilities and adaptability.

### Change management and communication

The application of AI in the industrial context often encounters resistance, stemming from scepticism caused by past failed efforts and the fear of potential job losses. Thus, proactive change management and transparent communication from the outset of the AI journey are instrumental to ensuring success and sustaining long-term results.

Executives and experts contributing to this guidebook highlighted the below enablers for successful change management and communication:

- **Leadership buy-in:** Leaders are aligned on the AI objectives, target picture, implementation roadmap and necessary changes, and they support the transformation.
- **Stakeholder engagement:** Stakeholders at all organizational levels have a clear understanding of their individual roles and their corresponding contributions to the success of AI.
- **Change culture:** An environment that supports and encourages the willingness to achieve the desired future state across all levels, with leaders promoting and role-modelling the desired behaviours.
- **Transparency and accessibility:** AI applications, including tailored stakeholder information materials, are available for all employees, thereby enhancing the acceptability of AI.
- **Communication strategy:** Authentic communication, spearheaded by leaders throughout the organization and encouraging a two-way dialogue that resonates with employees on a personal level.

Conscious of the importance of change management and employee buy-in for the success of a new AI solution, Körber Digital involved the affected employees right from the beginning of the adoption of the FactoryPal solution and embedded it in their daily shopfloor interactions. This has been a key success factor in the transformation, with the solution being scaled to more than 75 production lines and an overall equipment efficiency improvement of 30%.

### Ecosystem partnering

Considering the rapid evolution of AI, its inherent complexity, the depth of expertise needed and the scarcity of available experts, collaborating with different partners in the ecosystem and across value chains has proven to be a key enabler for success. This is especially true when contrasted with the daunting alternative of managing every aspect of the journey internally from the outset. Partnerships spanning the entire industrial and AI ecosystem can be instrumental in, for example:

- **Driving innovation:** Leveraging industry best practices and outside-in perspectives to provide fresh insights that are valuable for defining an AI vision and corresponding target picture with high-value applications, among other benefits.

- **Piloting:** Using digital factories as testbeds as they offer AI immersion sessions and opportunities to design, test and implement potential AI applications in real factory environments.

- **Capability building:** Collaborating with technology experts and academia to bridge existing capability gaps, such as by developing best-in-class data-processing capabilities on modern digital infrastructure or upskilling current talent.

### Legal compliance

The regulatory landscape is evolving and becoming increasingly mature (e.g. the EU AI Act),[13] strengthening the importance of ensuring legal compliance when implementing AI applications in industrial operations. With legal responsibilities varying across regions, the most effective approaches involve identifying relevant compliance markets and related policies and standards based on the scope and scale of applications implemented across the production network. Depending on the evaluation conducted and the risk level identified, registration with oversight regulatory bodies might be required. Additionally, it is important to maintain up-to-date technical documentation in order to showcase compliance efforts and provide comprehensive details, ranging from the system architecture to the risk management strategies in place.

## Technological foundations

Considering the digital nature of AI and the importance of data to its various applications, an adequate existing or new technology infrastructure needs to be in place to cater to AI requirements. Based on the consultations conducted, six dimensions are most relevant: data sourcing; data processing; applications and user interfaces; computing; connectivity; and cybersecurity. The first three dimensions are hierarchically interconnected, with data sourcing as the foundation, data processing in the intermediary position and applications and user interfaces as the top layer. The latter three dimensions – computing, connectivity and cybersecurity – run transversely to the first three.

### Data sourcing

AI applications are intrinsically reliant on data, making it crucial for manufacturers to ensure they have the necessary data sources readily available and accessible. These sources deliver different types of data – e.g. structured data such as part descriptions in product life-cycle management (PLM), or unstructured data such as time series data from sensors – and can typically be categorized into:

- **Field layer:** Providing data from programmable logic controllers and internet of things (IoT) devices and sensors, which can include, for example, real-time measurements of temperature, vibrations or pressures.

- **Control layer:** Composed of the manufacturing execution system (MES) and supervisory control and data acquisition (SCADA) systems.

- **Transactional layer:** Encompassing the enterprise resource planning (ERP) system and its warehouse management system (WMS), transport management system (TMS) and PLM, among others.

### Data processing

The data processing infrastructure makes the data sources available for analytics and AI applications. The infrastructure encompasses:

- **Ingestion:** Collecting and importing data from various sources, to be stored in a centralized database. Techniques such as edge analytics or IoT hubs are used to make (raw) data available for subsequent processing.

- **Processing:** Preparing and making data suitable for ML/DL algorithms and models – e.g. through data cleaning, filtering and contextualization.

- **Storage:** Storing (raw) data in a way that creates a single source of truth for all applications; for example, in a central data lake.

- **Delivery:** Constructing data pipelines to facilitate data flow and ensure its delivery to the point of use, such as specific AI models.

- **Archival and deletion:** Using data repositories to archive data and applying data governance for determinations about the ultimate deletion of data.

#### Applications and user interfaces

Another critical component of an AI-centric technological infrastructure in manufacturing pertains to the AI tools and applications themselves, including:

- **Intelligence layer:** Incorporating the algorithms and AI models, which adhere to the MLOps practices, including the model development, testing, validation, deployment and servicing.

- **Engagement layer:** Consisting of both general purpose and specialized applications, including interfaces that allow AI application users to interact with outcomes and insights in the manufacturing environment.

At Martur Fompak International, one important success factor in the implementation of an AI-based quality control system – which reduced the quality control process from 58 to 2–3 seconds – was to jointly develop with the employees a user interface tailored to the end user, which led to an increased usability and acceptance by the workforce.

#### Computing

AI applications, including the foundational analytical models such as ML and DL, often work with vast amounts of data, necessitating significant computing power to ensure timely data processing. The speed at which these AI applications operate is largely determined by the processors used, primarily central processing units (CPUs) and graphics processing units (GPUs). There are two primary approaches to providing AI with computing power: on-premises and cloud-based.

While the previously mentioned field and control layers almost always operate on-premises, numerous providers offer cloud solutions to handle parts of the data processing and execute the AI applications. With the emergence of generative AI solutions and the subsequent need to fine-tune foundational models using specific company data, several configurations become viable. For instance, an open-source foundational model might be employed, fine-tuned and operated within a private environment on-premises. Alternatively, a dedicated tenant within a provider's cloud platform could be used.

#### Connectivity

ML and DL algorithms often rely heavily on (near) real-time communication and data availability for many applications. As such, seamless networking and connectivity are essential, with both high bandwidth and low latency to ensure scalability. This can be achieved by establishing connectivity between plants via cloud links, within plants through wired or wireless communication and between assets using appropriate IoT protocols.

#### Cybersecurity

AI processes a vast amount of data, some of which can be sensitive. Ensuring data protection throughout the entire process necessitates a comprehensive cybersecurity strategy consisting of:

- Identity and access management (e.g. through authentication management)

- Data protection, detection and response (e.g. using firewalls and intrusion detection systems)

- Risk analysis and management

- Recovery planning

# Conclusion

The rapid evolution of AI is consistently yielding important innovations – such as the recent emergence of generative AI – offering tremendous potential to enhance productivity and production flexibility, drive sustainability and empower the workforce. However, while many companies have begun integrating AI into their operations, most have not realized their AI-related targets or fully unlocked its full value.

With many manufacturers facing challenges when implementing and scaling AI in their factories and supply chains, this white paper's guidebook aims to provide a systematic approach to harnessing the AI revolution in industrial operations. It describes the primary focus of each stage of the journey and presents a systematic approach to designing the AI target picture and implementing and scaling the associated AI applications and foundations:

– **Paving the way for success from AI in industrial operations:** Highlighting the importance of articulating an organization's long-term AI objectives and transformation principles as a starting point of the AI journey.

– **Mastering the AI journey across production networks:** Describing a step-by-step approach from the status quo assessment to the design, engineering, implementation and scaling of value-adding AI applications and required foundations.

– **Staying at the forefront of AI innovations:** Explaining the importance of conducting periodic AI reviews to continuously identify and integrate AI innovations and related opportunities.

Additionally, the guidebook elaborates on the enabling components that need to be at the foundation of the AI journey from both organizational and technological perspectives, illustrated by select examples.

Moving forward, the World Economic Forum will continue to shed light on the latest AI opportunities and innovations affecting manufacturing and supply chains, as well as providing a unique space for collaborations among industry leaders, technology experts and academics to deploy AI at scale in industrial operations, unlocking value for companies, society and the environment. Stakeholders are invited to join this initiative to share methodologies, incubate new pilots and disseminate insights. The purpose of this endeavour is to enable companies to successfully capture the full value of AI in industrial operations and to harness its ongoing innovations – today and in the future.

# Contributors

## World Economic Forum

**Maria Basso**
Centre Curator, Advanced Manufacturing and Supply Chains

**Memia Fendri**
Initiatives and Community Lead, Advanced Manufacturing and Supply Chains

**Kai-Frederic Seitz**
Principal, Boston Consulting Group, seconded to the World Economic Forum

**Kyriakos Triantafyllidis**
Head of Growth and Strategy, Centre for Advanced Manufacturing and Supply Chains

## Boston Consulting Group

**Daniel Küpper**
Managing Director and Senior Partner, Global (Co-)Lead BCG Manufacturing and Supply Chain, Boston Consulting Group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Strategic Alliances, Tulip Interfaces, UK

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Vice-President, Global Head of Advanced Manufacturing, TÜV SÜD, Germany

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Partner, Knife Capital, South Africa

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Chief Initiatives and Startups Officer, Consolidated Contractors International Company, Greece

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Global Head, Group Smart Manufacturing, Merck Group, Germany

**Efe Erdem**
Director, MESS Technology Platform, Turkish Employers' Association of Metal Industries (MESS), Türkiye

**Marco Freidl**
Head of Group Strategy and Business Development, Oerlikon, Switzerland

**Jürgen Gotepass**
Chief Strategy Officer Manufacturing, European Standardization & Industry Development Department, Huawei, Germany

**Andreas Hauser**
Chief Executive Officer, Digital Service, TÜV SÜD, Singapore

**Hagsoo Kim**
Business Development Manager, MakinaRocks, South Korea

**Dimitris Kiritsis**
Professor Emeritus of ICT for Sustainable Manufacturing, Ecole Polytechnique Fédérale de Lausanne, Switzerland

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Clark Distinguished Professor and Director of Industrial AI Center, Department of Mechanical Engineering, University of Maryland, USA

**Natan Linder**
Chief Executive Officer, Tulip Interfaces, USA

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Chief Executive Officer, Canvass AI, Canada

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Chief Executive Officer, causaLens, UK

**Torbjørn Netland**
Professor and Head of Chair of Production and Operations Management, ETH Zurich, Switzerland

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Chief Executive Officer, Versatile, USA

**Cyril Perducat**
Senior Vice-President and Chief Technology Officer, Rockwell Automation, USA

**Joris Poort,**
Chief Executive Officer, Rescale, USA

**Rajiv Puri**
Vice-President, Manufacturing Strategy, Solutions and Partnerships, Infosys, USA

**Shwetha Shetty**
Product Owner, SAP Digital Supply Chain Solutions, SAP, USA

**Daniel Szabo**
Chief Executive Officer, Koerber Digital, Germany

**Amogh Umbarkar**
Vice-President, SAP Product Engineering, SAP, USA

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Technology Governance Manager, Turkish Employers' Association of Metal Industries (MESS), Türkiye

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AI Research Engineer, Digital Service, TÜV SÜD, Singapore; Project Fellow seconded to the World Economic Forum

# Endnotes


1 World Economic Forum, *4 Ways Artificial Intelligence Could Transform Manufacturing*, January 2023: https://www.weforum.org/agenda/2023/01/4-ways-artificial-intelligence-manufacturing-davos2023/.

2 Boston Consulting Group, *Global Survey on AI in Industrial Operations 2023* (N=1,800), April 2023: https://www.bcg.com/about/partner-ecosystem/world-economic-forum/ai-project-survey.

3 World Economic Forum, *Beyond the Status Quo: How Generative AI Will Transform Industrial Operations*, June 2023: https://www.weforum.org/agenda/2023/06/how-generative-ai-will-transform-industrial-operations.

4 World Economic Forum, *4 Ways Artificial Intelligence Could Transform Manufacturing*, January 2023: https://www.weforum.org/agenda/2023/01/4-ways-artificial-intelligence-manufacturing-davos2023/.

5 World Economic Forum, *Unlocking Value from Artificial Intelligence in Manufacturing*, December 2022: https://www.weforum.org/whitepapers/unlocking-value-from-artificial-intelligence-in-manufacturing/.

6 Boston Consulting Group, *Global Survey on AI in Industrial Operations 2023* (N=1,800), April 2023: https://www.bcg.com/about/partner-ecosystem/world-economic-forum/ai-project-survey.

7 Ibid.

8 NVIDIA, NVIDIA Hopper, *Ampere GPUs Sweep Benchmarks in AI Training*, November 2022: https://blogs.nvidia.com/blog/2022/11/09/mlperf-ai-training-hpc-hopper/.

9 SAP, *Artificial Intelligence:* https://www.sap.com/products/artificial-intelligence/supply-chain.html?pdf-asset=7ac887f0-4d7e-0010-bca6-c68f7e60039b&page=1&source=social-atw-mailto.

10 World Economic Forum, *Unlocking Value from Artificial Intelligence in Manufacturing*, December 2022: https://www.weforum.org/whitepapers/unlocking-value-from-artificial-intelligence-in-manufacturing/.

11 IBM, *Machine Learning* (accessed September 2023): https://www.ibm.com/design/ai/basics/ml/#:~:text=Machine%20learning%20(ML)%20is%20a,teaching%20machines%20how%20to%20learn; IBM Research, *What is Generative AI?*, April 2023: https://research.ibm.com/blog/what-is-generative-AI.

12 World Economic Forum, *Unlocking Value from Artificial Intelligence in Manufacturing*, December 2022: https://www.weforum.org/whitepapers/unlocking-value-from-artificial-intelligence-in-manufacturing/

13 European Parliament, *EU AI Act: First Regulation on Artificial Intelligence*, June 2023: https://www.europarl.europa.eu/news/en/headlines/society/20230601STO93804/eu-ai-act-first-regulation-on-artificial-intelligence.

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World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744
contact@weforum.org
www.weforum.org