TATA CONSULTANCY SERVICES

TATA

Future-ready manufacturing: Powering the factories of the future

2025 TCS Digital Twindex Report Series

Foreword

Anupam Singhal
President,
Manufacturing, TCS

Historically, technology has always operated at the backend of manufacturing—driving efficiency, precision, and scale. However, today technology is at the front, driving business and delivering outcomes beyond operational excellence.

This is what makes manufacturing so exciting. We are entering a new era—where technology is not just redefining or enhancing processes but fundamentally transforming enterprises. At TCS, we call it **Future-Ready Manufacturing**—building organizations that can anticipate what is coming, adapt with speed and intelligence, and accelerate growth in a dynamic world.

This is not the vision of a distant future. It is here and now.

Digital twins are not new. They have been on the fringes of adoption for years. But in today's AI-driven context, they have become far more strategic. What began as simulation tools has now evolved into dynamic, real-time intelligent systems—fusing data, context, and computation to power continuous simulation, decision-making, and transformation at scale. They are becoming the foundational layer that connects physical operations with digital intelligence across the manufacturing value chain.

Across industries, we are seeing this acceleration. **Generative AI** is reshaping how we design, plan, and simulate. **Physical AI**—through Cobots, autonomous systems, and edge intelligence—is closing the loop between digital insight and physical action. **Agentic AI** is enabling systems to learn, reason, and self-optimize. **Quantum Computing** is poised to revolutionize how we simulate materials, energy, cyber security and logistics at a scale previously unimaginable.

Together, these capabilities are giving rise to a new kind of enterprise that senses continuously, learns autonomously, and predicts instead of reacting. An enterprise that is anticipatory by design—what we call **Design for Intelligence**—where intelligence is built into the very fabric of the enterprise.

This year's **Digital Twindex** explores this transformation in depth. It reflects the rich conversations we have had with our entire ecosystem of clients, partners, and colleagues who are not only adapting to this change but also leading the way in shaping it. From modular manufacturing systems that bring agility to production to AI copilots that empower people on the factory floor, this report captures a movement toward something profoundly different.

And yet, at its core, this is still a human story.

Future-Ready Manufacturing is not just about intelligence in machines—it is about intelligence that augments human capabilities. It is about giving teams the tools and perspectives to make faster, better decisions. It is about incorporating resilience, sustainability, and purpose into how we build the world around us.

I firmly believe that technology does not fulfill its purpose unless it improves the lives of everyday people—people like you and me. Its power lies not in complexity or scale, but in the meaningful impact it creates for citizens, industries, and society at large. Today, technology has an opportunity to make things more affordable, accessible to the underserved and underprivileged.

And that, to me, is technology at its best.

Executive champions

Featuring insights from TCS executives, clients, partners, and futurists, this issue of the TCS Digital Twindex analyzes the state of digital twin adoption in the manufacturing industry today—and the potential to further interconnect with AI to transform tomorrow.

Anupam Singhal
President,
Manufacturing, TCS

Zvi Feur
Senior Vice President,
Digital Manufacturing Software, and CEO, Siemens Digital Industries Software in Israel

Paulina Chmielarz
Director,
Digital & Innovation, Industrial Operations, JLR

Helenio Gilabert
Global Head of Offer Creation,
Industrial Automation Services, Schneider Electric

Nick Cassidy
Formula E Driver,
Jaguar TCS Racing

Naresh Mehta
Global Chief Technology Officer,
Manufacturing, TCS

Subhash Sakorikar
Global Head,
Industry Excellence, Manufacturing | TCS

Laksh Parthasarathy
Global Head,
Smart Mobility, Manufacturing | TCS

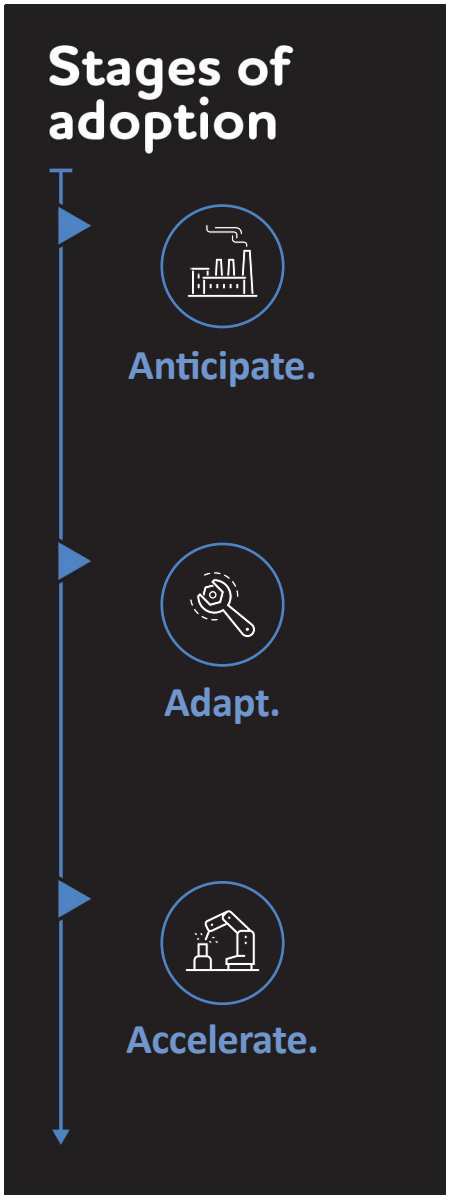
Michael Deittrick
Futurist,
TCS

Kevin Benedict
Futurist,
TCS

Executive summary

Manufacturing's future lies beyond machines, in the intelligent systems that connect them

In 2025, digital twins are evolving from simulation tools into strategic assets. They are enabling businesses to not just respond to change, but to anticipate, adapt, and accelerate in the face of disruption. This report explores how digital twin technology—when fused with GenAI, Physical AI, and agentic AI—is reinventing the very idea of manufacturing.



All factories strive for manufacturing excellence. Traditionally, manufacturers have relied on continuous improvements across processes, people, and technology to enhance operational performance. However, their approach to changing market conditions or evolving customer demands is often reactive—resulting in sub-optimal outcomes in efficiency, productivity, and quality.

An AI-led factory enables enterprises to become truly anticipatory. This means being equipped to predict, prepare for, and proactively address potential disruptions in operations—while dynamically adapting to market shifts. **Design for Intelligence** is a transformative framework that reimagines the modern factory as an anticipatory enterprise, moving beyond traditional automation to an AI-first model.

Such an enterprise fosters a factory that grows—where operational performance reflects its ability to continuously adapt to market demands, operational fluctuations, and technological advancements.

From aircraft assembly to smart factory rollouts, real-world deployments are proving the shift from a reactive enterprise to an anticipatory enterprise. At TCS, this shift is accelerated through our 'Design for Intelligence' approach. TCS-led transformations across the automotive, aerospace, and materials sectors are accelerating this evolution—building intelligent, adaptive factories that operate in real time.

Featuring perspectives from TCS leaders and clients, this Twindex offers a qualitative roadmap to what comes next: **the age of interconnected, human-centered, intelligent industry**.

Anticipate. Adapt. Accelerate.

Digital twins and AI empower organizations to anticipate disruption, adapt operations with intelligence, and accelerate transformation across every layer of manufacturing.

A new industrial playbook is being written—by intelligence that anticipates, adapts, and accelerates.

Key findings

Into Industry 4.5 and beyond

- Manufacturing is entering Industry 4.5—bridging automation and intelligence with sustainability and human-machine collaboration.
- GenAI enables anticipatory design; Physical AI bridges the virtual-physical divide; agentic AI powers autonomous optimization.
- Leading manufacturing companies are shifting from predictive to anticipatory manufacturing models.

Digital Twin as the real-time data fabric

- Digital twins have evolved into the real-time data fabric powering enterprise-wide decisions.
- They enable simulation, synthetic data generation, and predictive insights across operations.
- TCS helped a global auto OEM improve efficiency by 30% using integrated digital twin observability.

AI as an orchestrator of intelligence

- AI connects and activates insights from digital twins to drive real-time action.
- Use cases include predictive maintenance, workflow redesign, and factory-floor intelligence.
- GenAI adds reasoning; agentic AI drives autonomous learning and adaptation.

Modular and intelligent manufacturing

- Manufacturing is shifting toward modular and flexible models, supported by AI-powered micro-factories in some segments.
- These hubs leverage digital twins, GenAI, and Physical AI for responsive, localized production.
- They offer CapEx flexibility, real-time agility, and hyper-customization capabilities.

The human-AI symphony in manufacturing

- The factory of the future keeps humans in the loop—empowered, not replaced.
- Digital twins and agentic systems enable scenario planning and decision augmentation.
- Jaguar TCS Racing exemplifies the AI-human partnership in high-performance environments.

This is not an upgrade—it is a re-architecture of how enterprises think and act. It is the emergence of **sentient business enterprises**—sensing, simulating, and responding at speed and scale.

From supply chains to simulation, from shop floors to boardrooms, the story of digital twins is no longer speculative. It is happening now.

Chapter 1: Into Industry 4.5 and beyond

We are now entering a transition decade for manufacturing—not a continuation of Industry 4.0, but a steppingstone toward something profoundly different: **Industry 4.5.** This is not just a technical evolution—it is a redefinition of how industry anticipates, adapts, and accelerates.

Where Industry 4.0 emphasized automation and connectivity, **Industry 4.5 marks the transition toward real-time intelligence, human-AI collaboration, and sustainability—not yet Industry 5.0, but the groundwork for it**. It is the threshold between automation and autonomy—between a reactive enterprise and an anticipatory one, built with a 'Design for Intelligence' mindset.

> Digital twins are a game-changer in our AI journey. They unlock vast amounts of new data, introduce fresh data categories, and open up entirely new scenarios for exploration.

Paulina Chmielarz
Director,
Digital & Innovation,
Industrial Operations, JLR

As Michael Deittrick notes, *"The biggest challenge is not whether AI or digital twins can deliver value—it's whether leaders are willing to rethink their business models."* This rethinking is already underway.

Companies like **Airbus** are using digital twin technology to reimagine aircraft assembly processes, reducing both time and cost. **BMW**, among others, is building out intelligent production environments that anticipate issues before they arise. **Agentic AI systems**, already emerging, will further evolve this landscape by learning, reasoning, and acting on their own within defined boundaries.

Meanwhile, **GenAI is being embedded in design and planning**, accelerating how simulations inform factory setup, maintenance cycles, and even sustainability assessments. **Physical AI**—through edge devices, Cobots, and vision systems—is dissolving the boundary between digital command and physical execution.

Quantum computing will be a force multiplier for digital twins. As quantum capabilities mature, manufacturers will be able to simulate material science, energy usage, and logistics flows with exponentially greater speed and precision for complex problems—making twins more predictive, more adaptive, and more valuable than ever.

The result is a world where factories do not merely operate—they evolve. Real-time signals lead to real-time action. Production lines adapt. Cobots collaborate. And humans orchestrate.

Industry 4.5 is not a destination. It is a capability milestone. Enterprises that embrace Industry 4.5 are developing the ability to sense operational conditions in real time, simulate outcomes dynamically, and scale intelligent decision-making across their value chain.

It marks the moment when systems become smart enough to reconfigure themselves, when operations become sustainable by design, and when resilience is no longer an afterthought—but a feature of the architecture itself.

Chapter 2: Digital twin as the real-time data fabric

"Digital twins are a game-changer in our AI journey. They unlock vast amounts of new data, introduce fresh data categories, and open up entirely new scenarios for exploration." – Paulina Chmielarz, Director, Digital & Innovation, Industrial Operations, JLR

Digital twins are no longer just digital representations—they are becoming the **real-time data fabric of the enterprise**. Their evolution from static models to real-time intelligence systems is powering a new era of predictive, adaptive, and autonomous operations.

At their core, digital twins bring together data, context, and computation. But what makes them truly transformative today is their integration with **GenAI, agentic AI, and Physical AI**—enabling not just simulation but real-time action. They are the substrate on which AI thrives and scales.

> If it's not digitized, you cannot automate it. If you cannot automate it, you cannot deploy intelligence on top of it.

Helenio Gilabert
Global Head of Offer Creation, Industrial Automation Services, Schneider Electric

"If it's not digitized, you cannot automate it. If you cannot automate it, you cannot deploy intelligence on top of it." – Helenio Gilabert, Schneider Electric

Digital twins now power everything from individual machine diagnostics to ecosystem-level orchestration. Their value lies in their ability to create **synthetic data** that trains AI systems, continuously simulate "what-if" scenarios, and optimize operations before anything is physically built or changed.

"Digital twins in combination with emerging concepts of Model-Based Systems Engineering, digital thread, and concurrent engineering, provide an unprecedented opportunity to build the products first time right, at the right cost, and shorten time to market." – Subhash Sakorikar, Global Head – Industry Excellence, Manufacturing, TCS

TCS' work with a major North American auto OEM shows this in action—by unifying digital twin observability across plants, the client achieved up to **30% improvement in efficiency**, along with significant reductions in downtime and operating cost.

The roadmap to scale includes:

- **Product twins** for rapid prototyping and testing
- **Process twins** to optimize workflows in real-time
- **Plant twins** for layout efficiency and throughput
- **Supply chain twins** to simulate multi-tier logistics dynamics

IDC projects that by 2027, more than 35% of G2000 companies will use supply chain orchestration tools powered by digital twins—unlocking a **15% increase in responsiveness**.

As Laksh Parthasarathy, Global Head - Smart Mobility, Manufacturing, TCS puts it: *"Digital Twins have to reflect the physical world in real-time, all the time. If it doesn't reflect reality tomorrow, it's already obsolete."* To truly unlock AI at scale, digital twins are essential. They are not just the backbone—they are the **connective tissue between intelligence and execution**. Enterprises are using them to sense conditions across production, simulate optimal responses, and scale coordinated actions across systems.

> "Imagine a situation within the next decade where AI agents could be helping us make better decisions... help us identify problems before they happen. We can go and fix these problems (and) keep the production running smoothly... We can make sure all the logistics arrive at the right spot at the right time. This is where I see a big, big change.

Zvi Feur
Senior Vice President, Digital Manufacturing Software, and CEO, Siemens Digital Industries Software in Israel

Chapter 3: AI as an orchestrator of intelligence

"AI should not operate in isolation. It should integrate seamlessly with existing processes to become a fundamental part of future-facing ecosystems." – Paulina Chmielarz, Director, Digital & Innovation, Industrial Operations, JLR

Artificial Intelligence is no longer a functional tool—it is the force that connects, activates, and optimizes the entire digital manufacturing ecosystem. Its role is no longer limited to isolated use cases; AI now operates as an orchestration layer across operations.

When embedded within digital twins, AI transforms data into decisions. And with the rise of **GenAI and agentic AI**, these decisions are becoming more autonomous, explainable, and adaptive in real time.

"Imagine a situation within the next decade where AI agents could be helping us make better decisions...help us identify problems before they happen. We can go and fix these problems (and) keep the production running smoothly... We can make sure all the logistics arrive at the right spot at the right time. This is where I see a big, big change." - Zvi Feuer, Senior Vice President, Digital Manufacturing Software, and CEO Siemens Digital Industries Software in Israel

In TCS' work with a global seat manufacturer, AI models were trained to detect surface-level defects like wrinkles during assembly—enabling near-instant quality control and throughput optimization. These are not just point solutions; they're signals of a seismic shift.

"While predictive AI is a crucial starting point, the real transformation is in empowering AI to detect early, act decisively, and foster self-healing capabilities. This journey, from prediction to prevention to self-healing, is the future of intelligent systems." – Anupam Singhal, President – Manufacturing, TCS

AI use cases across the factory floor include:

- **Predictive maintenance** that extends asset lifespan and reduces downtime
- **Dynamic workflow adjustments** based on real-time signals
- **AI-assisted design**, configuration, and production planning

Agentic AI elevates this further. These are AI systems that can interpret context, act on goals, and adapt their own behavior—allowing manufacturers to shift from reactive decisions to continuous optimization.

GenAI adds reasoning and language-based interfaces, helping teams across engineering, operations, and supply chain interact with their data—not through code, but conversation.

At scale, AI doesn't replace the factory. It makes it think. It integrates **cobots, vision systems**, and **sensor intelligence** into a responsive mesh—where machines are not just told what to do, they understand why they are doing it. AI is no longer the engine inside automation. It is the **orchestrator of intelligence across the enterprise**. It enables enterprises to sense disruptions, simulate responses, and scale autonomous decisions across their factory ecosystems.

> "While predictive AI is a crucial starting point, the real transformation is in empowering AI to detect early, act decisively, and foster self-healing capabilities. This journey, from prediction to prevention to self-healing, is the future of intelligent systems.

Anupam Singhal
President, Manufacturing, TCS

Chapter 4: Modular and flexible manufacturing

"For cost-effective personalization of products, it's about achieving higher-level customization and lower-level commonization. Manufacturers will need digital twins and AI more than ever before to enable customization of products while maintaining efficiency, ensuring that supply chains, production lines, and even the final product can be tailored dynamically." – Subhash Sakorikar, Global Head – Industry Excellence, Manufacturing, TCS

The traditional model of large, centralized, capital-intensive factories is giving way to a new paradigm: **modular and flexible manufacturing**—powered by AI, digital twins, and adaptive systems. These are small, smart, and scalable manufacturing units that bring production closer to demand—enabling localized customization, faster time to market, and real-time responsiveness.

Modular and flexible factories thrive on the convergence of digital twins, Physical AI, and GenAI. They simulate, adapt, and operate with minimal human intervention—while still keeping humans in control of decision-making.

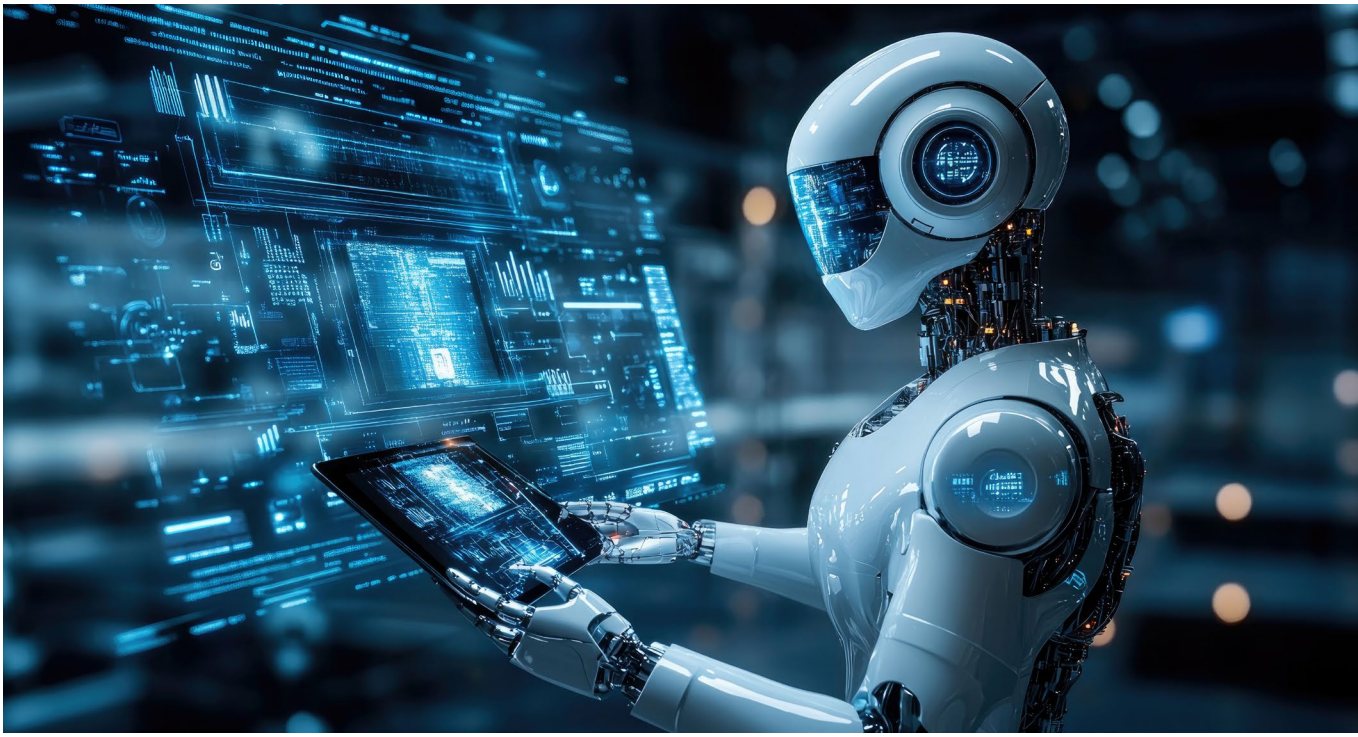
TCS' work with manufacturers is already enabling shifts toward distributed manufacturing models. Imagine a former warehouse transformed into a plug-and-play production unit, equipped with 3D printing, vision AI, and connected Cobots—capable of scaling up or down based on real-time market signals.

"Imagine a warehouse is no longer a warehouse. It's now converted into a manufacturing center that 3D prints everything on demand." – Michael Deittrick, Futurist, TCS

The benefits of this shift include:

- **Reduced CapEx:** Lower upfront investments with modular, scalable setups
- **On-demand production:** Minimized inventory, faster responsiveness
- **Resilient operations:** Less vulnerable to supply chain shocks
- **Sustainability gains:** Proximity to consumption reduces emissions

Physical AI—via edge devices and autonomous robots—enables micro-factories to act immediately on real-time conditions. GenAI supports adaptive planning, while digital twins allow continuous performance tuning across the network.



This is not just about smaller factories. It is about **smarter, distributed manufacturing**—where intelligence is embedded at every node. The result: production becomes more agile, customer-centric, and future-ready. These factories are designed to sense local demand, simulate production variables in real time, and scale output with precision and agility.

"Manufacturing is evolving from automation to intelligent symbiosis. Driven by Physical AI, situational awareness, and Agentic AI, Software-Defined Factories, conceived with a 'Design for Intelligence' mindset, will create adaptive, self-optimizing production environments that maximize throughput and OEE." – Naresh Mehta, Global CTO – Manufacturing, TCS

Chapter 5: The human-AI symphony in manufacturing

"People need to feel included in the process. When interacting with powerful AI, they should see it as a natural extension of their work—something that integrates seamlessly into everyday business operations." – Paulina Chmielarz, Director, Digital & Innovation, Industrial Operations, JLR

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The future of manufacturing is not lights-out—it is **human-led and AI-augmented**. In an era of advanced automation, what sets leading factories apart is not the absence of people, but the elevation of their role through intelligent technologies.

Digital twins and AI are empowering humans to focus on strategic tasks: scenario planning, exception handling, continuous improvement, and innovation. Rather than replacing workers, AI is augmenting human capability.

"Our vision isn't for AI to dictate, but to partner. The future thrives on the synergy of AI and human intelligence." – Naresh Mehta, Global CTO – Manufacturing, TCS

This model is now reaching the factory floor—where technicians, planners, and operators are gaining AI copilots that enhance decision-making, planning, and real-time responsiveness.

Agentic AI systems proactively guide human workers through complex decision-making. GenAI provides natural language interfaces, enabling cross-functional teams to engage with data and simulations without technical barriers. Cobots and physical AI systems collaborate with workers safely and intuitively.

> Cobots become truly transformative when combined with vision systems, predictive analytics, and new interfaces between humans and machines. The real opportunity is not just automating existing tasks, it's redesigning how humans and intelligent systems collaborate to improve productivity and safety.

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"Cobots become truly transformative when combined with vision systems, predictive analytics, and new interfaces between humans and machines. The real opportunity is not just automating existing tasks, it's redesigning how humans and intelligent systems collaborate to improve productivity and safety." – Helenio Gilabert, Global Head of Offer Creation, Industrial Automation Services, Schneider Electric

The factory of the future is designed not just for efficiency—but for **human empowerment, safety, and resilience**.

Key shifts include:

- **From automation to augmentation:** AI supports decision-making, not just execution
- **From interfaces to interaction:** Conversational AI lowers the barrier to intelligence
- **From training to trust:** AI builds confidence by learning from human feedback

As manufacturing enters this new phase, **people will not be displaced by AI—they will be amplified by it**.

This is the true promise of Industry 4.5 and beyond: human-led, AI-powered manufacturing that is intuitive, intelligent, and adaptive. Workers sense anomalies, simulate multiple outcomes, and scale intelligent decisions with AI copilots at their side.

We already see this orchestration in adjacent high-performance environments. At Jaguar TCS Racing, drivers simulate race scenarios using digital twins to optimize strategy long before hitting the track. It is this same synergy of intelligence and instinct that is beginning to shape the manufacturing floor.

Working with cobots

Precision assembly & human assistance

Cobots will assist human workers in complex assembly tasks, handling repetitive, high-precision work while humans focus on quality control and problem-solving.

Example: In an AI-powered micro-factory, Cobots could perform real-time adjustments to assembly line configurations, enabling rapid shifts between customized production runs without halting operations.

Predictive maintenance & AI-guided repairs

Cobots equipped with AI-driven sensors will continuously monitor machine health, identifying potential failures before they occur.

Example: A factory operator overseeing production can receive alerts from Cobots when performance anomalies are detected, allowing proactive maintenance without unexpected downtime.

Workplace safety & ergonomic support

Cobots will handle physically demanding tasks, reducing strain on human workers and preventing workplace injuries.

Example: In a future-ready automotive plant, Cobots could assist technicians by lifting and positioning heavy components, allowing workers to focus on precision tasks rather than repetitive physical labor.

Adaptive manufacturing & real-time decision support

Cobots will interact with AI-powered digital twins, providing real-time feedback on production conditions and optimizing workflow efficiency.

Example: In a dynamic production environment, if a supply chain delay occurs, Cobots could automatically adjust assembly schedules based on AI-generated insights, ensuring seamless production continuity.

Conclusion: The sentient enterprise is already here

The future of manufacturing is not in the machines, but in the intelligent networks they create.

What began as a technological ambition is now a business necessity. Digital twins—combined with GenAI, agentic AI, and Physical AI—have moved beyond experimentation. They are reshaping how factories function, how people work, and how decisions are made across the industrial value chain.

The shift from reactive to anticipatory, from centralization to intelligent decentralization, and from automation to augmentation is not a future scenario. It is unfolding now.

Forward-looking manufacturers are not just digitizing their operations. They are building sentient, sustainable enterprises—systems that anticipate, adapt, accelerate, and respond continuously. And as this transformation accelerates, the question for every CxO becomes clear:

Are you deploying technology—or designing intelligence into the very fabric of your enterprise?

This Twindex 2025 is a reflection of where we are—and a provocation for where we need to go next.

About the report

This edition of the **TCS Digital Twindex Report** explores how digital twin technologies—when fused with GenAI, Physical AI, and agentic AI—are not just reshaping manufacturing, but redefining the very architecture of industrial intelligence. It captures how organizations are moving from automation to anticipation, evolving into intelligent, adaptive enterprises through approaches such as **TCS' Design for Intelligence**, which is helping reimagine how factories think, learn, and respond.

The report is grounded in **qualitative research**, developed through curated, future-focused conversations between TCS clients, ecosystem partners, senior leadership, and futurists. These dialogues surfaced the priorities and provocations that are shaping the manufacturing sector's next leap forward.

The **TCS Digital Twindex Report** reflects **TCS' vision for Future-Ready Manufacturing**—offering a strategic lens into how intelligence is no longer an overlay, but a foundation for manufacturing transformation in the decade ahead.

About Tata Consultancy Services (TCS)

Tata Consultancy Services (TCS) (BSE: 532540, NSE: TCS) is a digital transformation and technology partner of choice for industry-leading organizations worldwide. Since its inception in 1968, TCS has upheld the highest standards of innovation, engineering excellence, and customer service.

Rooted in the heritage of the Tata Group, TCS is focused on creating long term value for its clients, its investors, its employees, and the community at large. With a highly skilled workforce of more than 607,000 consultants in 55 countries and 180 service delivery centers across the world, the company has been recognized as a top employer in six continents. With the ability to rapidly apply and scale new technologies, the company has built long term partnerships with its clients—helping them emerge as perpetually adaptive enterprises. Many of these relationships have endured into decades and navigated every technology cycle, from mainframes in the 1970s to Artificial Intelligence today.

TCS sponsors 15 of the world's most prestigious marathons and endurance events, including the TCS New York City Marathon, TCS London Marathon, and TCS Sydney Marathon with a focus on promoting health, sustainability, and community empowerment. TCS generated consolidated revenues of US $29 billion in the fiscal year ended March 31, 2024.

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