Physical AI & Humanoids:

A Generational Opportunity to Reshape the Global Productivity Equation

March 2026

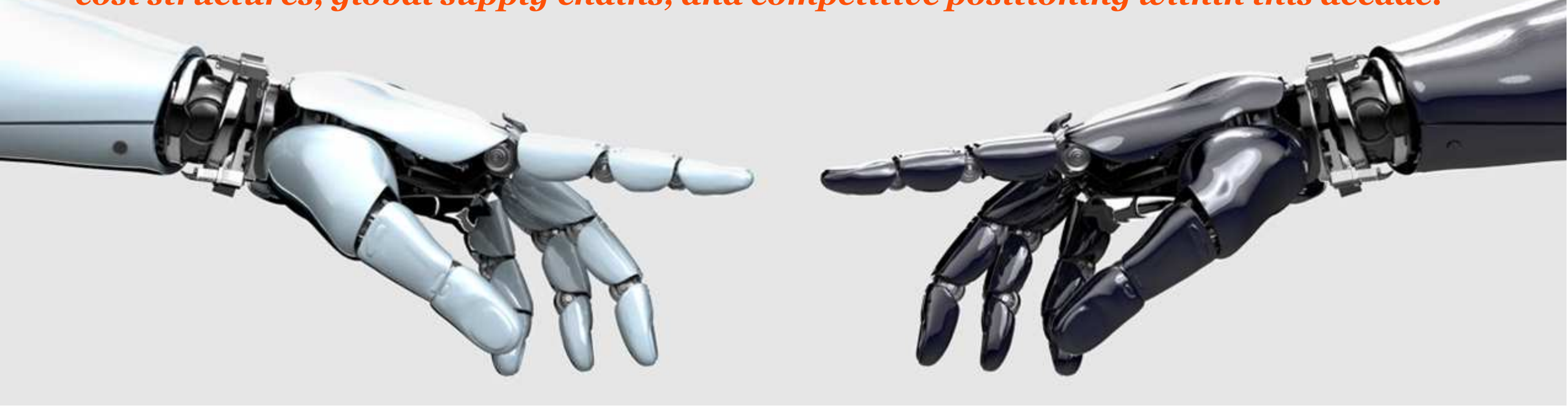
Executive summary

Economic nationalism and supply chain realignment are driving unprecedented demand for domestic industrial capability. However, this transformation cannot be sustained without a fundamental step-change in productivity.

Physical AI represents the most significant opportunity to address this challenge. It integrates Industry 4.0 solutions, Digital Twins, and robotics—including Humanoids—all powered by artificial intelligence to sense, reason, and act in physical environments.

- **Physical AI promises the potential for normalizing labour cost per unit across geographies -** At scale, “human + robot” collaboration can compress labour cost differences across geographies; arguably, labour costs could become comparable across Toronto, Cleveland, or Mexico City, reshaping global supply chains.
- **An industry model where existing jobs continue to grow marginally while Humanoids augment capacity -** For most industries, labour cost growth is about 40% of revenue and closely correlates with the revenue curve, but with the emergence of Physical AI, the labour cost curve can begin to decouple from the revenue curve through productivity gains.
- **Emergence of a marketplace for pre-trained Humanoid models -** An ecosystem in which industry, developers and hardware suppliers collaborate to develop pre-trained models that can be licensed or sold enabling to Robot-as-a-Service models. Task based trained models can then scale across sites and sectors.
- **Humanoids will scale faster than traditional Robotics -** Physical AI provides a potential universal platform for Humanoids to operate in environments designed for Humans. With lower retrofit requirements, brownfield deployments may be early targets for value creation, especially for "automation-resistant” work.
- **Moving from linear to compounding productivity growth -** Moving away from scaling the workforce solely through training, Humanoids can improve over time through accumulated data, software deployments across fleets, and hardware upgrades across operations, geographies and industries.
- **Constraints to address early –** Limited training data for imitation and reinforcement learning, legacy system integration, and inconsistent engineering & process standards can further limit efficacy and slow scale.

Physical AI is not a distant vision—it is an emerging reality that will redefine industrial cost structures, global supply chains, and competitive positioning within this decade.



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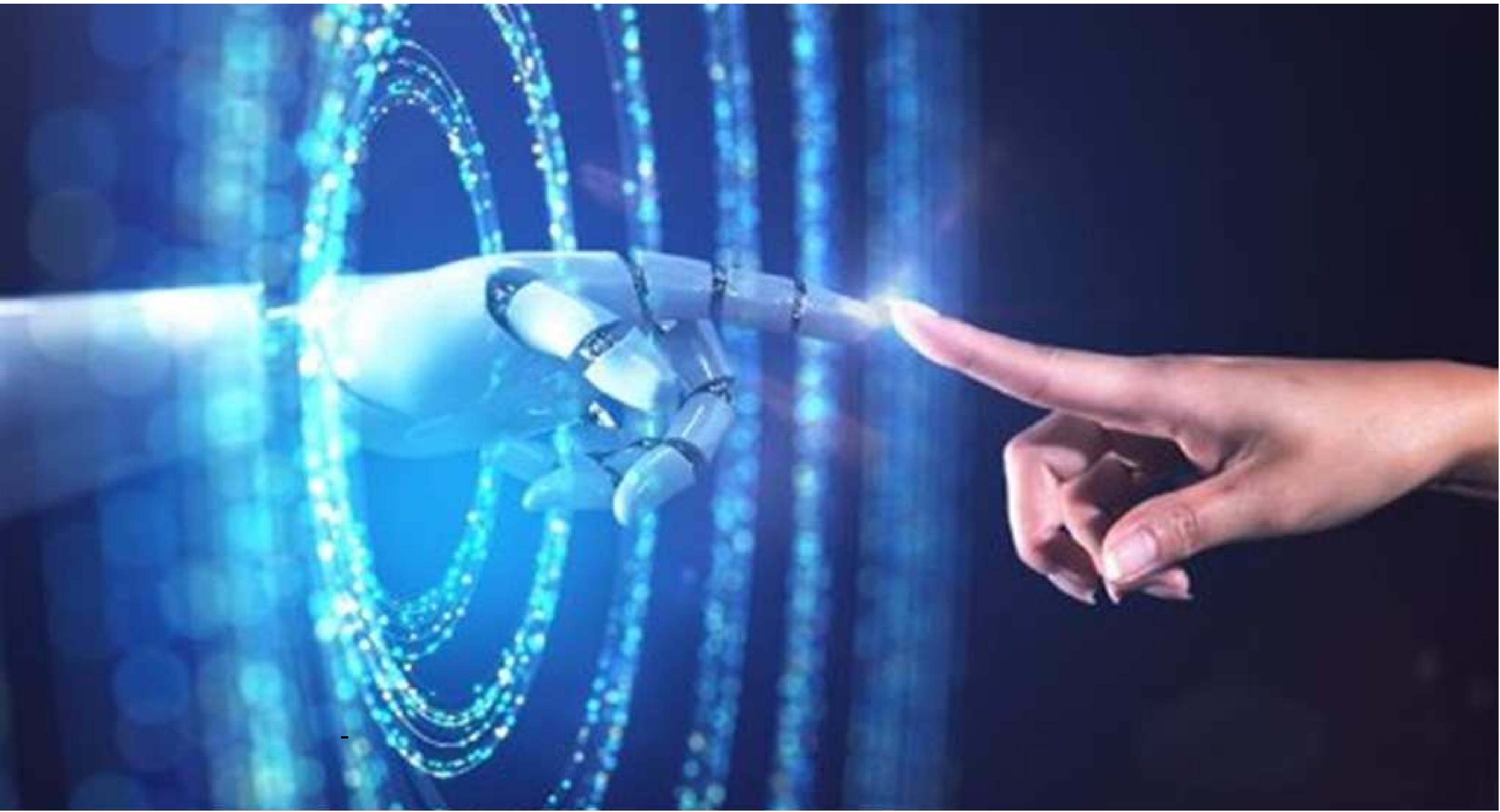
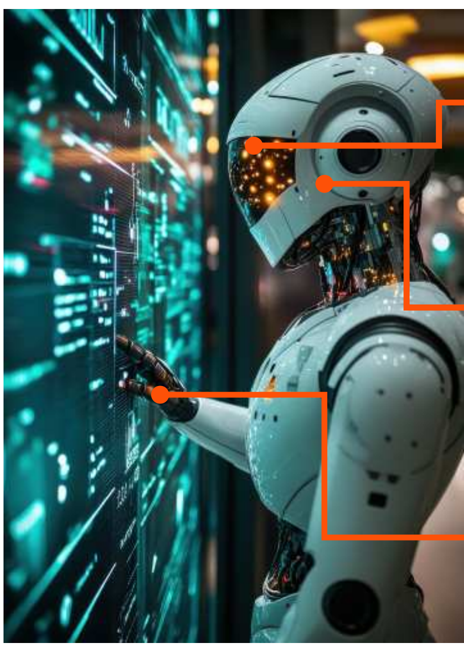


Chapter 1: Physical AI and Productivity Imperative

Economic nationalism is reshaping global supply chains and manufacturing footprints as countries seek greater resilience, security, and domestic capability. This realignment will be difficult to sustain without a step change in productivity, improved labour efficiency, and reduced input costs. Physical AI is poised to become central to this next industrial narrative.

AI investment is accelerating, alongside a healthy skepticism about enterprise adoption. As foundational models and agentic systems mature, they will increasingly enable Physical AI to drive a step change in productivity and operational efficiency.

What is Physical AI? In the most simplistic terms, it is the integration of Industry 4.0 solutions and digital twin solutions powered by AI. Digital twins have been discussed for over a decade, yet adoption remains uneven. The promise has always been “sense - predict – act" but the barrier is trust: organizations hesitate to let the digital twin drive action without human oversight. Physical AI represents a fundamental departure from previous waves of automation. It combines three capabilities that have historically required human workers:



The world of “**Sense**” is evolving and getting more predictable. Advanced sensing systems—computer vision, LiDAR, tactile sensors, and multimodal perception—allow machines to understand unstructured environments in real-time.

The ability to “**Predict**” has fundamentally enhanced with the access and maturity of AI models. Large foundation models and specialized AI enable systems to interpret context, make decisions under uncertainty, and adapt to novel situations without explicit programming.

Lastly “**Act**” which was previously reliant on OT systems to execute tasks has been transformed by robotics, including Humanoids and quadrupeds. Sophisticated actuators, dexterous manipulation, and locomotion systems can now translate intelligence into physical work across diverse environments.

This triad enables automation of tasks previously considered "automation-resistant“; activities that demand judgment, adaptability, and physical dexterity. Humanoid robots, in particular, represent a potential general-purpose platform for physical AI, because they can operate in environments designed for people with minimal retrofit. Their value proposition is versatility: the ability to switch between tasks, use human-scale tools and workstations, and collaborate safely alongside workers. With these capabilities in place, the question becomes: why hasn't productivity kept pace with technological progress?

The Productivity Paradox of the Digital Age

The global economy faces a structural productivity challenge that threatens long-term prosperity. Advanced economies have experienced a marked slowdown in productivity growth since the mid-2000s, with annual gains falling from historical averages of 2-3% to barely 1% in many nations.

Despite major investments in IT, cloud, and digital transformation over the past two decades, these gains have largely failed to translate into sustained productivity improvements across the broader economy. This "Solow Paradox"—named after economist Robert Solow's observation that "computers are everywhere except in the productivity statistics"—persists because of:

- **Limited Translation into Physical Operations:** Many interventions remain concentrated in information workflows, while a large share of GDP depends on physical activities where digitization has a slower impact.
- **Measurement Challenges:** Traditional metrics struggle to capture quality improvements and new forms of value creation.
- **Implementation Gaps:** Technology adoption requires complementary organizational changes that take decades to diffuse.

Sector	Share of Global GDP	Share of Employment
Manufacturing	16%	14%
Construction	6%	7%
Agriculture	4%	27%
Mining and Metals	3%	1%
Transportation and Logistics	5%	5%
Healthcare	6%	8%
Total Asset Intensive Sector	40%	62%

Source: PwC Research across various 3rd Party Public Databases

Chapter 2: Business Case of Physical AI reshaping the Industrial Cost Curve

Physical AI has the potential to reshape industrial economics by altering the relationship between labour, capital, and output. At scale, “human + robot” collaboration can reduce labour cost differences across geographies; arguably, labour costs will become roughly the same in Toronto, Cleveland, or Mexico City, reshaping global supply chains.

Physical AI can drive a step change in unit costs across asset intensive sectors where labour costs represent 30% to 50% of the operating cost – by augmenting workers, improving throughput, and reducing variability. The implication is not that geography becomes irrelevant, but that the “labour arbitrage” driver weakens as the share of work performed by autonomous systems increases.

Importantly, the business case is not centered on workforce reduction instead of top-line growth with a constant or reducing the cost of goods sold (COGS). The near-term value is driven by augmentation while enabling retraining and role evolution as adoption grows. Let us break down the business case in more detail. The primary value will come from four areas:

Direct Labour Augmentation: A single worker supervising multiple autonomous systems multiplies effective labour supply. Human-robot collaboration combines human judgment with machine precision and endurance. Skills transfer becomes faster as AI systems can demonstrate and guide.

Throughput Per Dollar of Capital: Physical AI introduces a new category of productive capital. Unlike traditional automation, these systems can be rapidly retrained and redeployed. 24/7 operation without fatigue extends effective capital utilization.

New Operating Models: Physical AI enables new ways of running operations e.g. semi-autonomous zones, flexible cells, and lights-out micro-environments by redesigning workflows around human-robot collaboration, with safety and exception handling built in.

Ecosystem of Learning Effects: Data generated by physical AI systems accelerates learning across entire industries. Best practices propagate through AI model updates rather than human training. Cross-sector applications multiply returns on R&D investment.

How Physical AI changes the cost curve

01

From variable labour costs to fixed capital economics: Traditional operations have high variable labour costs that scale with output. Physical AI converts these costs into semi-fixed to fixed capital costs, fundamentally changing operating leverage:

- Higher break-even points but superior marginal economics
- Stronger competitive position for high-volume producers with significantly reduced cost/unit
- Industry consolidation toward scaled players feeding the re-shoring of supply chains
- Decoupling cost curve with revenue curve will help reduce the average cost/hour or cost/unit in operations

Physical AI and Humanoids can augment the workforce, helping flatten the cost curve and improve competitiveness as revenue scales.

02

From labour arbitrage to capital and execution competition: For decades, global manufacturing has sought lowest-cost labor. Physical AI shifts competition towards:

- Access to capital and technology by supporting onboarding new Physical AI technologies
- Speed and discipline of adoption fed by pre-trained models
- Integration capability (workflows, systems, data)
- Ecosystem advantages (suppliers, software, talent) which is a significant focus area for most global economies

This shift may enable re-shoring of production to advanced economies where capital is abundant, and technology leadership is strong.

03

From linear to compounding improvement: Human labour productivity generally improves incrementally (1-3% annually through learning and tools). Physical AI productivity can improve exponentially through:

- Software updates deployed across entire fleets
- Accumulated data improving model performance
- Hardware upgrades and component improvements
- Standardization of workflows and exception handling

Early adopters can accumulate compounding advantages provided they build the foundations to scale safely and reliably.

Where adoption begins: practical industry entry points

Physical AI will not arrive everywhere at once. Early deployment is most credible in structured environments where work is repetitive; safety exposure is material, and workflows are well-defined. We anticipate about 25-35 standard tasks across material handling, manual operations, safety monitoring, routine inspections driven by repeatable model training creating the pathway for more complex automation-resistant tasks.

Manufacturing

Manufacturing presents the most immediate and extensive opportunity, building on decades of automation maturity. Early deployments cluster around: machine tending, line-side replenishment, packaging, kitting, end-of-line handling.

Mining

Early deployments are likely to emphasize inspection and remote support before high dexterity tasks.

Today Robotics are used for safety application but may eventually transition to productivity.

Construction

Likely early deployments: material carry, site cleanup, tool fetching, and repetitive drilling in controlled areas.

Agriculture

Potential early deployments: packhouse handling, greenhouse support, internal logistics, and simple inspection/sorting workflows.

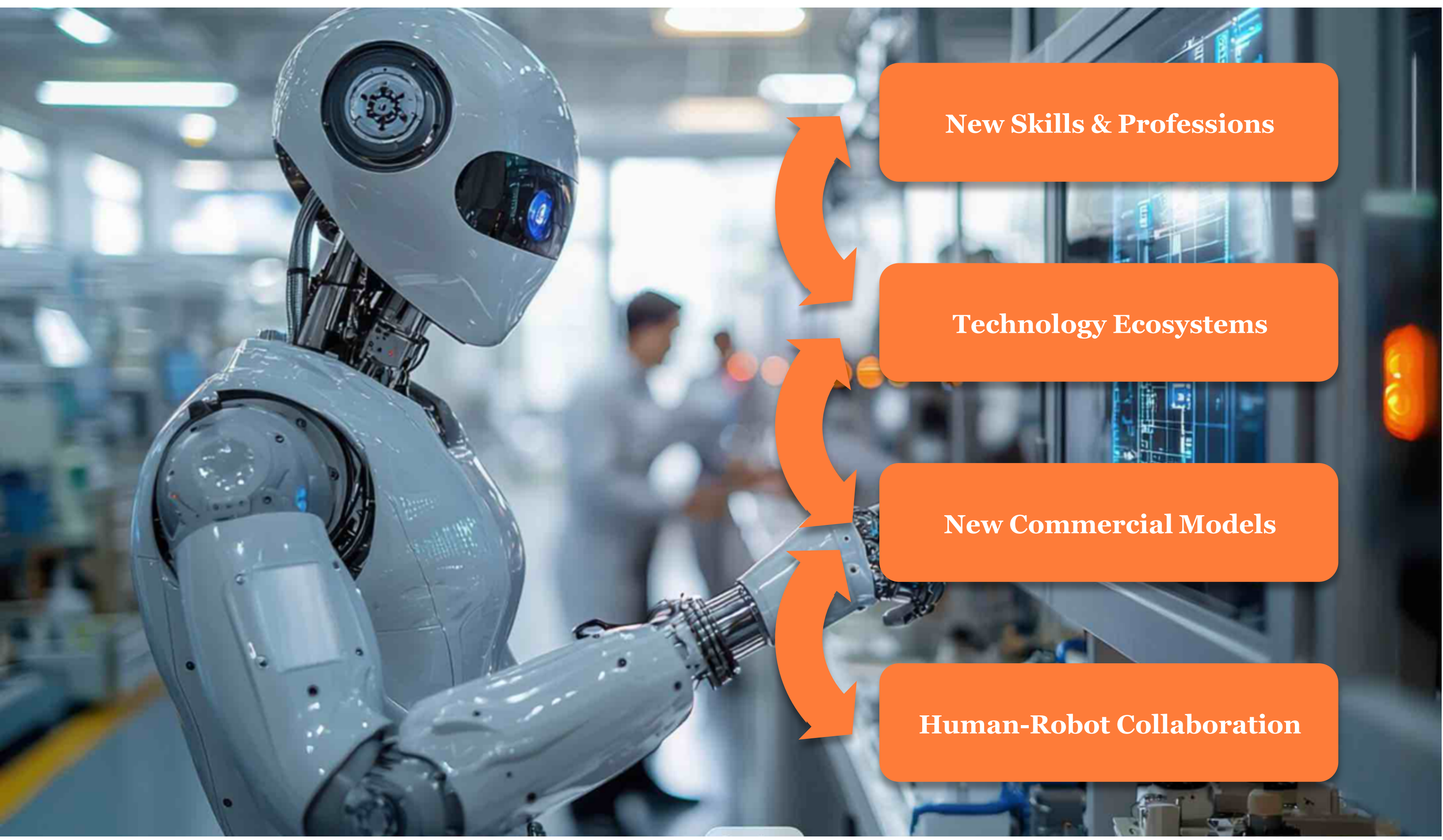
Across these sectors, operations labour commonly represents a significant share of operating cost (often cited in the 30-50% range, depending on the process and commodity). Physical AI's near-term economic promise is therefore strongest where labour constraints, safety exposure and variability directly limit throughput and service levels.

Chapter 3: The new opportunity spectrum

Beyond large and mid-sized industrial companies, the opportunity spectrum for Physical AI extends across an ecosystem of industries, institutions, and associations – and will likely spur new entrants across the physical value chain: infrastructure and energy, components (including semiconductors), hardware manufacturers, model and AI software providers, and scale enablers that specialize in deployment, integration, and operations. It also includes the end-user community (operators, maintainers, safety leaders, and frontline teams) who will shape adoption.

We have already seen a surge in semiconductor demand driven by AI; and even as we publish this article, investment in Physical AI continues to accelerate.

So where are the opportunity buckets?



01 Era of New Skills and Professions

- Universities will need to emphasize new courses focused on upskilling students to train, build and maintain this new stream jobs to build, operate, and maintain Physical AI systems (robotics engineering, autonomy, perception, simulation).
- Reskilling the existing workforce – expanded programs for skilled trades (electricians, plumbers, mechanics etc.) to support deployment, maintenance, and safety operations.

02 Ecosystem of Other Companies

- Hardware supplier communities catering to the Robotics customers – from the component manufacturers to the Robots to the custom tools and fixture manufacturing to enable various use cases.
- Software ecosystem: This domain of companies that develop new software – operating models, training data and models, simulation products and services.
- Besides end customers, this group are the biggest beneficiaries of the Physical AI boom given the exponential demand for new products and services with no legacy pricing baggage or barriers, which will allow for innovative pricing models.

03 New Commercial Models

- Marketplace and Collaboration Platform for Trained Robot Models: Emergence of new revenue streams for sharing models on repetitive tasks across Humanoids across sectors and assets (e.g. if we can train a Humanoid robot to organize tools on a rack at the end of a shift - recognizing each item, tidying the worksite, and preparing it for the next crew - that same model can be scaled across manufacturing, maintenance, and many other customer environments). This will drive adoption and scaling via marketplace platforms.
- Robot-as-a-Service (RaaS) models reducing upfront costs and supporting the overall model build and maturity which will help control the input cost predictability and make industries more competitive.

04 Human-Robot Collaboration

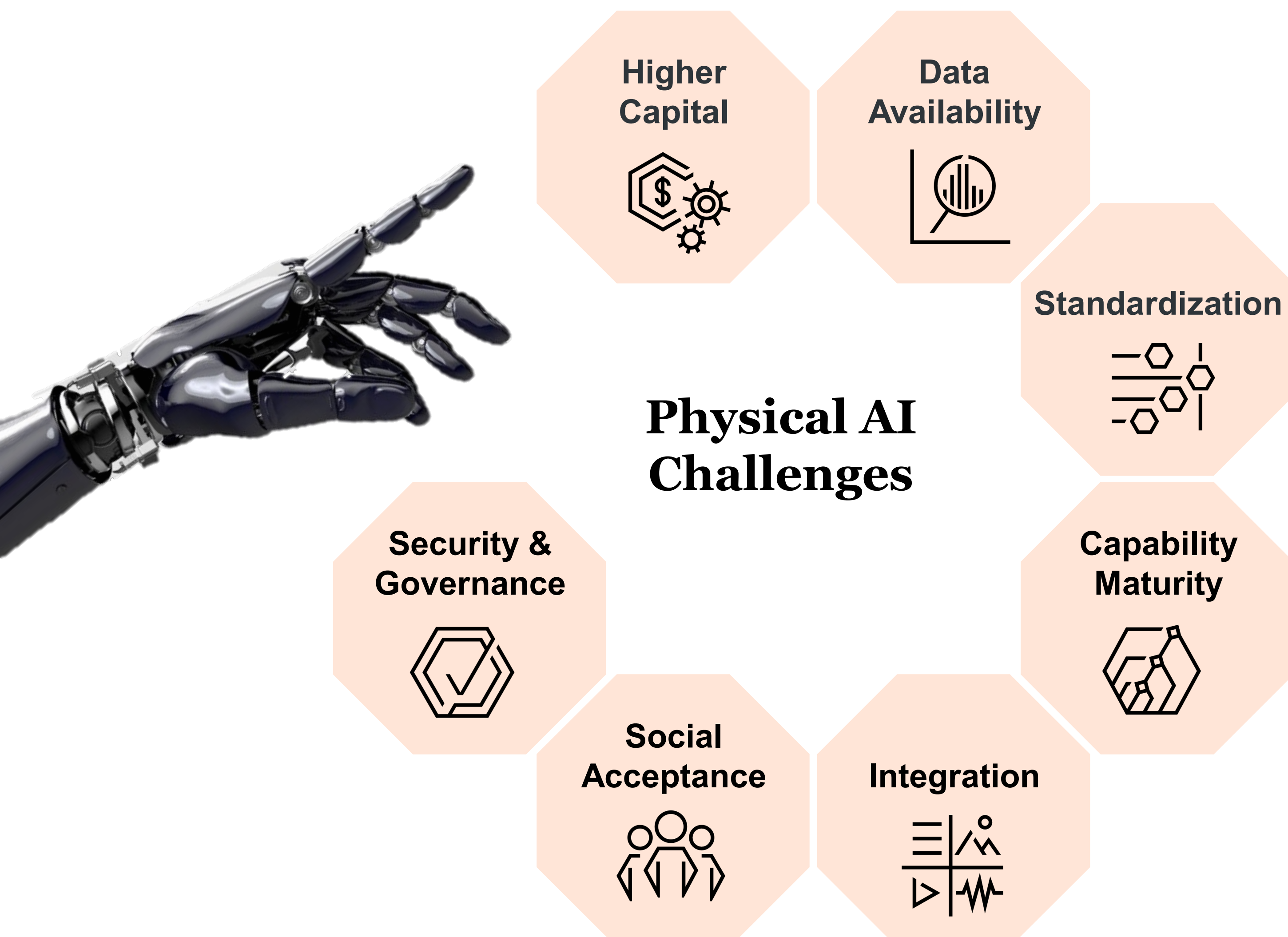
- Collaborative working of Humans and Robots will help foster trust across the ecosystem. Human-robot trust is both an opportunity and challenge for scaling physical systems. A collaborative operating model will begin fostering the trust equation where “Job loss” is not the existential crisis for humans.
- With increased adoption of Physical AI, this trust coupled with strong governance and cyber controls will need to be in place to engage in next level of role augmentation with unions and other industrial clients.

Chapter 4: Challenges and constraints

Before turning to the challenges of Physical AI, it is worth reflecting on why IoT and digital twins did not scale as quickly as many market projections suggested, despite their perceived value. The primary barriers were high upfront capital requirements, higher than expected operating costs, unclear ROI in many environments, and a persistent skills gap across industries, particularly in OT/IT integration and advanced analytics capabilities.

Turning to Physical AI, we consider potential challenges and how they can be addressed collectively. Learning from the challenges of Digital Twins, Physical AI poses a higher chance of success but with a longer runway ahead.

Industry, Perception and Technical Challenges



01 For early adopters, the business case over the short term tends to focus on higher capital without an assurance of the benefits capture

Current cost structures pose considerable challenges to adoption, especially for small and medium-sized enterprises. Deployment expenses encompass hardware, software, model training, calibrations, integration, testing, workforce training, operational adjustments, process changes, and the resultant learning curve, as well as the cultural transformation required within teams. Humanoid robots remain expensive today, with costs varying widely on configuration and out of the box capabilities. However, meaningful cost reductions are expected as production scales.

02 Availability of data and information to train models and Robots

Unlike the back-office AI model that are built with years of structured and unstructured data, Humanoid Robots learn through Imitation learning (learn by watching), Reinforced Learning (learn from trial and error), Simulation model etc. However, access to data (video files of repeatable tasks being done over the years) is not easily stored or available to enable imitation learning.

03 Lack of standardization across parts, processes, and engineering standards

Today, only a limited number of companies have invested time and effort in standardizing end to end flows. By standardization we mean engineering standards, when they integrate into your design of parts, process and assets and finally into standard operating procedures and quality inspection. Automotive, select aerospace manufacturing, and nuclear operators are generally more advanced in this area. Other sectors such as mining, energy, transmission/distribution and transportation, often compensate for this gap through additional labour and localized workarounds, which can deliver short-term continuity but become harder to sustain than targeted capital investment as labour tightens.

04 Maturity of hardware and capabilities

This is one challenge that we anticipate will be the least challenging to overcome. The pace of progress in AI has been rapid, and Physical AI is benefiting from the same momentum. Significant investment across major North American and Chinese Robot Manufacturers and accelerating maturity in the ancillary industries is likely to expand access to capable hardware and software platforms in 12-18 months.

In parallel, with the investments in Agentic AI and other Physical AI chips and models, the software capabilities will accelerate ahead of all other challenges.

05 Integration with legacy systems

Even in the Industry 4.0 era, many asset heavy sectors are heavily reliant on legacy applications built 20+ years ago. These systems often persist because modernization business cases are hard to justify, the platforms are stable, business rules are deeply embedded, cybersecurity risks are high, and regulatory constraints can slow change. As a result, many core operational capabilities remain in OT environments and have not fully adopted IoT connectivity and advanced sensing at scale.

This challenge is further compounded by legacy equipment that lacks connectivity and standardized interfaces, making integration with Physical AI systems more complex and costly.

The opportunity is to define pragmatic "leapfrog" pathways: introducing Physical AI in targeted workflows while building the minimum viable foundations needed to scale. In some environments, this may allow organizations to avoid large, monolithic system replacements upfront while accepting that value realization will ramp as integration maturity increases.

06 Perception and social acceptance

Physical AI will only scale if it is adopted with the workforce, not to the workforce. Robotics is often interpreted through a job-displacement lens, especially when organizations lead with cost narratives. A more pragmatic and constructive frame is augmentation: improving safety, reducing fatigue and variability, and enabling workers to supervise and improve systems that raise overall capacity.

Building social acceptance requires visible partnership: (1) co-designing with frontline teams, (2) creating capability pathways, and (3) being transparent about change.

Ultimately, perception is earned through trust, participation, and outcomes. Organizations that treat Physical AI as a joint operating model rather than a technology rollout will scale faster and more sustainably.

07 Redefine the physical security and governance frameworks

While many of the barriers outlined above can be addressed over time, scaling Physical AI will require industry-wide collaboration to modernize cybersecurity, physical security, and governance for autonomous systems. In practice, this means:

a. Established workflows and processes require significant redesign.

b. IT infrastructure and data systems need upgrading.

c. Quality, Governance compliance frameworks must be extended.

d. Safety systems require recertification.

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