

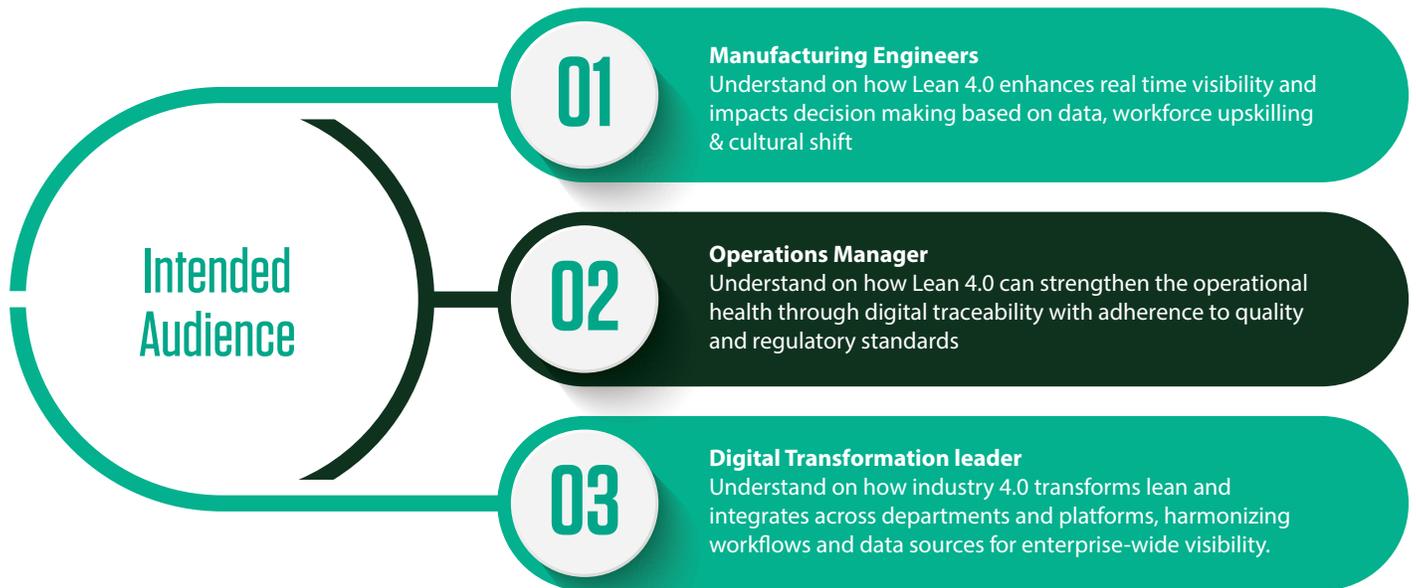


## REIMAGINING LEAN IN THE DIGITAL ERA

Lean 4.0 drives the convergence of Lean principles with Industry 4.0 technologies, creating a transformative approach to delivering operational excellence in the digital age. While traditional Lean focuses on waste reduction, continuous improvement and value creation, Industry 4.0 furnishes intelligent automation, data-driven decision-making, and cyber-physical systems.

Lean 4.0 leverages tools such as IoT, AI, and edge computing to enhance real-time visibility into operations, improve responsiveness across the value chain, eliminate digital inefficiencies, enable real-time decision-making, and empower connected workers in a Lean manufacturing setup. It leverages the best of both worlds - the efficiency of traditional Lean and the power of Industry 4.0 as it is strategically important for sustainable growth, competitive advantage and resilience in an increasingly competitive, complex and digitalized world.





## Lean Manufacturing: An overview

Toyota<sup>1</sup> introduced Lean manufacturing in the mid-20<sup>th</sup> century and has since evolved significantly. Known as the Toyota Production System (TPS), it aims to improve efficiency while eliminating waste in manufacturing processes with a focus on Just-In-Time (JIT) production.

While Lean tools work well across various industry segments, they are less applicable in custom manufacturing, highly regulated industries, luxury goods production, and early-stage R & D, among others, primarily due to unique operational needs and compliance requirements.

## The Three M's of Lean

Lean management centers around three key principles: Muda, Mura and Muri—collectively called the “Three M’s”. Originating in Japan’s Toyota Production System (TPS), these concepts identify different types of inefficiencies within a business and can simplify operations, cut waste and boost performance.

### MUDA (Wastes)

It highlights activities that don’t add value to the customer and should be eliminated. The eight key wastes, remembered as DOWNTIME, are: Defects (quality issues creating rework or scrap), Overproduction (making more than needed), Waiting (idle resources), Nonutilized Resources (underused people/machines), Transportation (unnecessary movement of goods), Inventory (excess raw/work-in-progress/finished goods), Motion (unnecessary movement of people), and Excess Processing (doing more work than required). Addressing these waste helps streamline production, reduce costs, and boost efficiency, forming the backbone of Lean principles.

### MURA (Unevenness)

It represents operational inconsistency or irregularity, such as fluctuating workloads, unpredictable demand, or uneven production schedules. It leads to inefficiencies, bottlenecks, and resource stress.

### MURI (Overburden)

It refers to excessive strain on people, machines, or systems beyond their capacity.

It causes breakdowns, errors, fatigue and safety risks.



# The Evolution of Lean

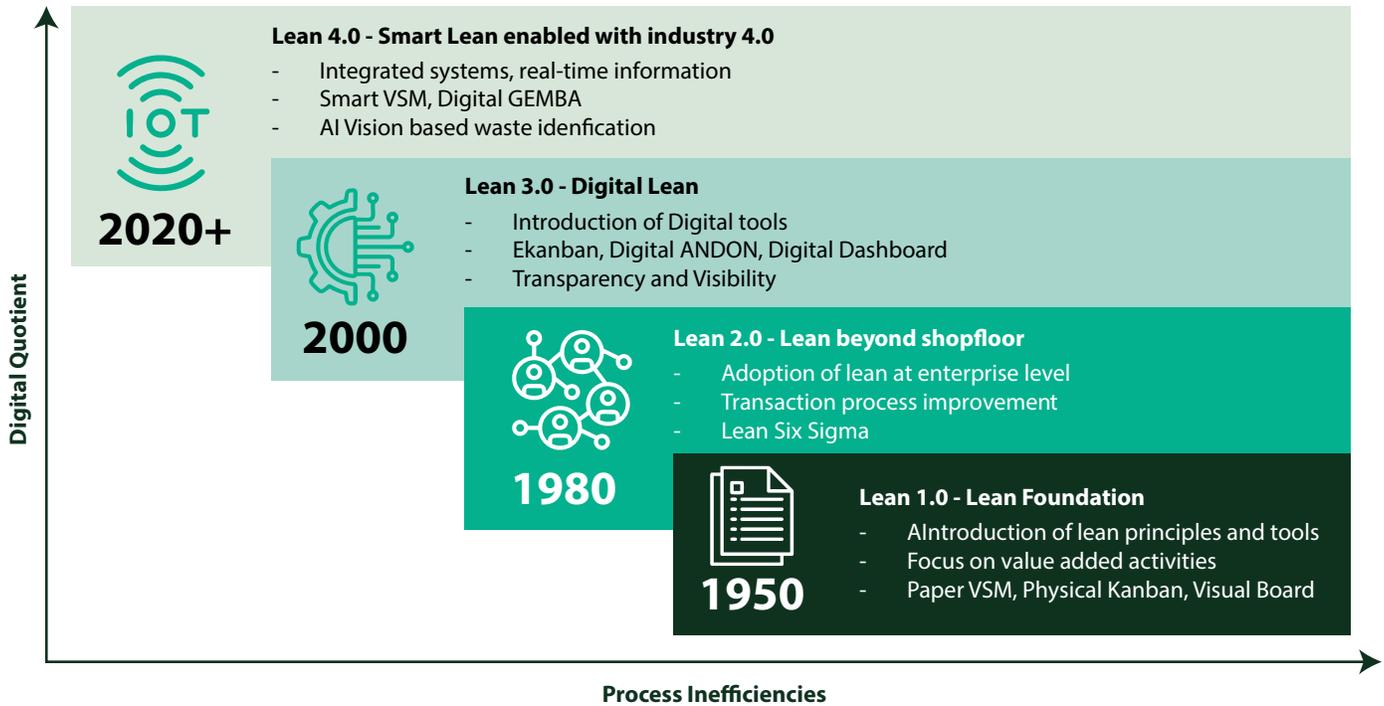


Figure 2: Evolution of Lean 4.0

## Lean 1.0

Lean 1.0 intended to eliminate waste (Muda), reduce variability (Mura) and avoid overburden (Muri) on the shop floor. It focused on improving flow and efficiency, leveraging tools such as Kaizen, Kanban, Poka-yoke, Standard work, Value stream mapping, 5S, and SMED. It involves manual processes, physical Gemba walks, paper-based VSM, and visual management boards to yield customer value.

## Lean 2.0

Lean 1.0 improved productivity by removing non-value-added tasks and reducing costs. By the late 1990s, Lean 2.0 emerged. These principles were applied across services, IT, and offices, and Lean Six Sigma added a quality improvement dimension. It encouraged ongoing process enhancements and standardization to boost efficiency.

## Lean 3.0

In the new millennium, traditional Lean evolved into digital Lean by adopting tools such as ERP systems and a digital dashboard. As manufacturers turned digital, it embodied a hybrid culture, painting traditional Lean on a digital canvas. It improved process visibility, transparency across the value chain, and decision-making while maintaining Lean principles.

## Lean 4.0

In its third decade, the convergence of digital Lean and Industry 4.0 is imminent. It helps incubate Lean 4.0, a complete transformation of traditional Lean through the lens of I4.0 frameworks, shaping up digital-first operational excellence. Technologies such as IoT, AI/ML, Cloud computing, Computer Vision, and AR/VR have transformed Lean by enabling real-time data visibility and predictive analytics, achieving agility, resilience and efficiency. Digital GEMBA helps monitor shop floors using sensors and AR/VR, while Digital VSM provides real-time and dynamic updates. Products such as e-Kanban and Digital ANDON boards automated replenishment and signaling, enabling smarter and connected processes.

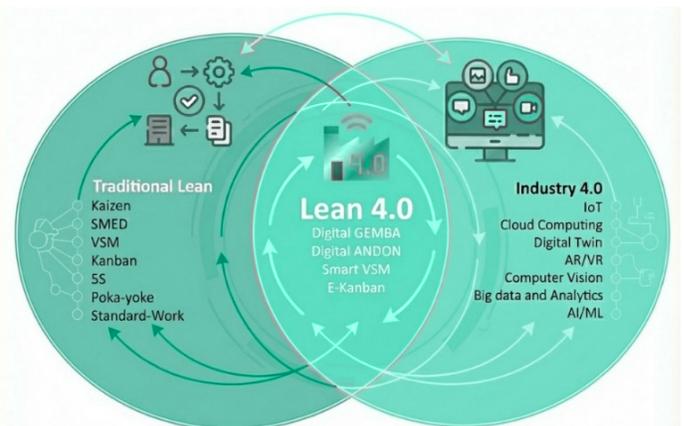


Figure 3: Emergence of Lean 4.0

# Navigating into Lean 4.0

This paper provides a comprehensive evaluation of Lean 4.0 versus traditional Lean approaches, clearly delineating variations across essential Lean tools.



Figure 4: The Lean 4.0 Wheel

As industries focus on processes, people, and operations, we have organized various Lean tools into three distinct categories: process optimization, user experience and operations management, while illustrating the significance of Lean 4.0 through its business outcomes.

# Process Optimization

Lean 4.0 represents an unprecedented evolution of traditional Lean methodologies by integrating advanced digital technologies, such as AR/VR, AI, IoT and predictive analytics, into established Lean tools. This enables real-time data collection, predictive insights, immersive experiences and smart automation, resulting in enhanced process optimization. The adoption of digital solutions not only streamline operations but also helps prevent errors and enables quicker setup analyses.

| Tool Category   | Tool  | Traditional Lean                        | Lean 4.0   | Business Outcomes                    |
|---|---|---|--|--------------------------------------|
|  | <b>Gemba Walk:</b> Shopfloor observation and process monitoring | Physical visits, manual input capture   | Digital Gemba via apps, AR/VR, AI-based monitoring | Remote assessment, real-time updates |
|   | <b>Process Mapping:</b> Mapping and analyzing workflows         | Static paper-based VSM                  | Digital VSM with simulation and analytics          | Dynamic updates, scenario modeling   |
|   | <b>Poka-Yoke:</b> Error-proofing mechanisms                     | Physical devices like jigs and fixtures | Sensor-based detection, AI alerts                  | Smart error prevention               |
|   | <b>SMED:</b> Setup Time Reduction                               | Manual stopwatch analysis               | IoT-enabled tracking, predictive optimization      | Real-time setup analytics            |

# User Experience

User experience in Lean 4.0 is amplified through intuitive digital interfaces, augmented reality (AR/VR) applications, and seamless connectivity across devices and locations. AR/VR enables immersive training and real-time guidance on the shop floor, reducing errors and onboarding time, resulting in a safer, more cognitively engaging, and more productive user environment and higher satisfaction and performance.

| Tool Category   | Tool   | Traditional Lean  | Lean 4.0  | Business Outcomes                          |
|---|--|---|---|--|
|  | <b>Visual Management:</b> Real-time KPI tracking and alerts        | Physical Kanban, manual boards, pressed Andon lights      | E-Kanban, digital dashboards, automated alerts                                | Real-time data, remote access              |
|   | <b>Standard Work:</b> SOPs and training methods                    | Printed SOPs, manual checklists, classroom video training | AR/VR-based training, digital instructions                                    | Adaptive learning, fewer defects/incidents |
|   | <b>Kaizen (Continuous Improvement):</b> Continuous improvement     | Manual workshops, suggestion boxes                        | AI-driven suggestions, digital feedback platforms                             | Real-time insights, data-driven decisions  |
|   | <b>Workforce Empowerment:</b> Team collaboration and communication | Manual communication, visual boards                       | Mobile collaboration tools, instant assistance, AR/VR for enhanced experience | Remote collaboration, instant updates      |

# Operations Management

Lean 4.0 upgrades core Lean tools with advanced digital technologies, boosting efficiency across operations. Root cause analysis uses AI-driven automated data logging for quicker and more accurate diagnostics. It enables superior asset maintenance with predictive algorithms, next-gen quality control with computer vision for real-time defect detection, and digital safety audits to eliminate labor incidents. Overall, it leads to faster problem-solving, reduces disruptions, improves accuracy, and creates a safer workplace, illustrating Lean 4.0's transformative impact.

| Tool Category   | Tool   | Traditional Lean                      | Lean 4.0  | Business Outcomes                   |
|---|--|---------------------------------------|---|-------------------------------------|
| <b>Operations Management</b><br> | <b>Root Cause Analysis:</b><br>Problem-solving and diagnostics | Fishbone, 5 Whys, manual data capture | AI-assisted, automated data logging                         | Faster, accurate diagnostics        |
|   | <b>Maintenance:</b><br>Equipment upkeep                        | Preventive schedules                  | Predictive maintenance via IoT and AI                       | Reduced downtime, proactive alerts  |
|   | <b>Quality Control:</b><br>Inspection and defect detection     | Manual stopwatch analysis             | Automated inspection, ML-based defect detection             | Higher accuracy, real time alerts   |
|   | <b>Safety Audits:</b> Workplace safety monitoring              | Manual audits, operator vigilance     | Digitized audits, IoT sensors, wearables, AI risk detection | Lower injury rates, fewer incidents |

To summarize, Lean 4.0 shall facilitate a game changing digital process and manufacturing execution on the floor through a harmonious blend of process efficiencies and digital intelligence delivering: -

- Data-Driven continuous improvements with advanced analytics and dashboards facilitating real-time decision-making
- Connected cyber-physical systems creating a smart factory environment
- Agile and flexible production through smart scheduling and adaptive manufacturing systems
- Predictive & Prescriptive maintenance leveraging IoT sensors and AI models
- Digital Twin & simulation driving scenarios testing and optimizations.



# Implementation Approach

Migrating into Lean 4.0 from its predecessors starts with targeted, small-scale, high-value solutions that deliver rapid results and clear benefits. By first addressing manageable problems using appropriate Lean tools such as Kaizen events, Poka-Yoke, or quick standardization efforts, organizations can generate momentum and demonstrate value, motivating broader adoption across operations. The process involves an initial assessment to determine the current state of lean (CMO) and digital maturity, thereby establishing benchmarks. Once the necessary data and infrastructure are in place, a pilot program (MVP) can be launched to validate value realization before scaling.

As implementation scales out, integrating advanced technologies such as smart sensors, predictive maintenance, and AI-driven analytics may take more time but unlock greater long-term gains. Sustaining these improvements depends on fostering a culture of continuous improvement, engaging teams, and embedding Lean principles throughout the organization for lasting efficiency and agility.

The timelines outlined below represent the duration of key phases of the Lean 4.0 migration; however, these may vary depending on the industry's current Lean and digital maturity levels, among other factors.

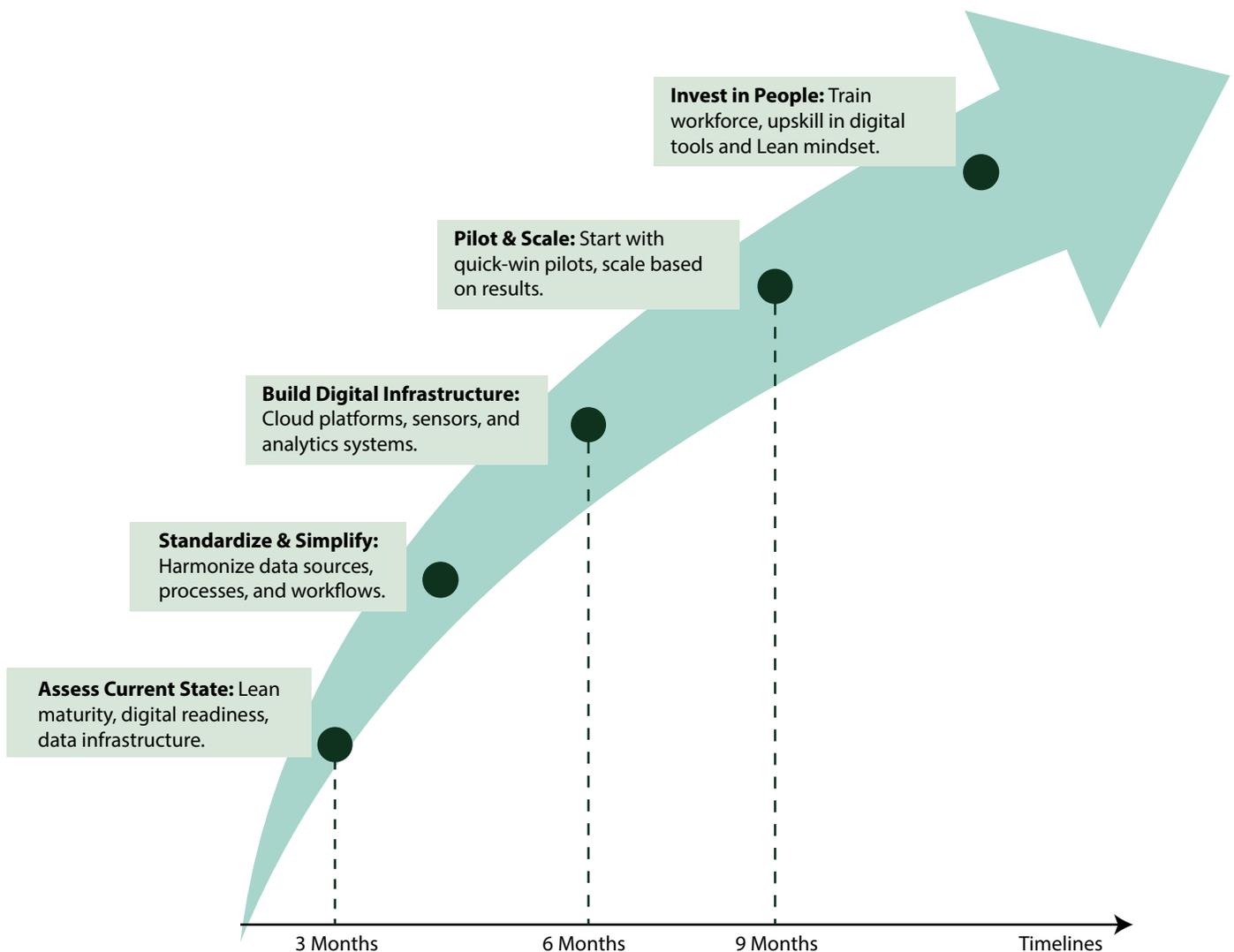
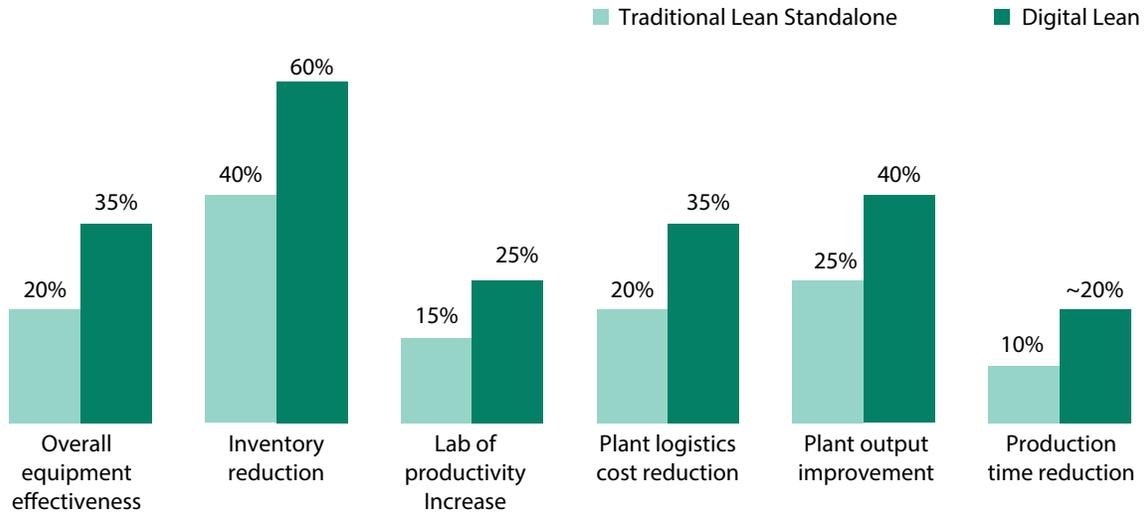


Figure 5: Implementation approach

# Lean 4.0 Market Analysis

The Lean services market is forecast to reach USD 15.3 billion by 2033<sup>2</sup>, registering a 4.8% CAGR between 2026 and 2033, fueled by increasing investments in process improvement and cost optimization, and the adoption of Lean 4.0 measures.

Lean 4.0, or Digital Lean, can significantly enhance savings from traditional lean.



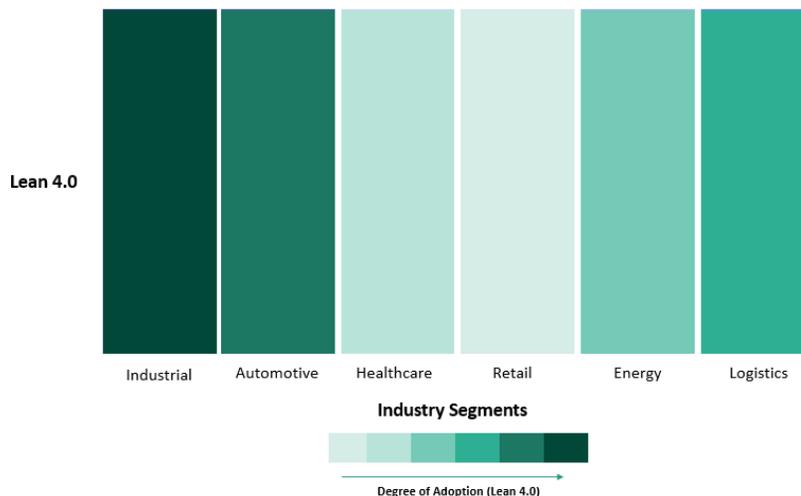
**Combining digital and lean initiatives can reduce costs by up to 30% versus**

Graph 1: Operational benefits of Lean 4.0 over Traditional Lean<sup>3</sup>

## Industry Outlook

Lean manufacturing focuses on value-added activities while minimizing waste to improve efficiency and maximize customer value. Beyond automotive and industrial manufacturing sectors, others such as retail, healthcare, energy, and logistics are experiencing significant improvements by embracing Lean 4.0. These organizations are realizing benefits, including enhanced operational efficiency, reduced waste, and faster response times to market changes, thereby demonstrating agility and resilience in the face of disruptions.

Most of the industry segments benefit from predictive maintenance and improved asset utilization, while logistics providers achieve optimized supply chain operations and increased delivery reliability. Retailers are leveraging Lean 4.0 to improve inventory management, reduce costs and personalize customer experience. The integration of digital technologies with Lean principles empowers these industries to drive continuous improvement while adapting swiftly to evolving business demands.



Graph 2: Lean 4.0 and its adoption across industry segments



## Adoption of Lean 4.0 in Pharmaceuticals

The adoption of Lean 4.0 in the pharmaceutical industry resulted in over 50% improvement in quality and a 55%-60% reduction in inventory waste<sup>5</sup>. Technologies such as robotics, sensors, AI, IoT, RFID, blockchain and predictive analytics helped boost compliance and make production more responsive. Despite these advances, challenges remain in integrating new technologies with older systems and ensuring the personnel adapt to the changing workplace.

By automating traditional manual tasks such as product inspections, documentation and inventory tracking, Lean 4.0 effectively reduces human error and labor-intensive processes. Robotics and computer vision have replaced manual inspection routines, enabling continuous monitoring for defects and improving consistency. Predictive analytics and IoT streamline decision-making and allow quicker responses to production issues that once relied on time-consuming manual data collection. These advancements directly address common industry challenges by increasing operational efficiency, reducing bottlenecks, and ensuring compliance, while also requiring strategic efforts to upskill employees and integrate legacy equipment with new digital solutions.



## Adoption of Lean 4.0 in Automotive

As in Pharmaceuticals, Lean 4.0 implementation with strong leadership focus has resulted in a ~30% increase in Overall Equipment Effectiveness (OEE), ~55-60% improvement in quality, and reductions of ~60% in setup time and ~45% in lead time across the automotive sector<sup>6</sup>. Key enablers such as IoT, AI, and real-time analytics, when integrated with Lean principles, have revolutionized the automotive industry.

Deployment of Lean 4.0 technologies—such as robotic systems, digital twins, and AI-driven optimization—yielded measurable improvements in operational performance.

**Productivity gains-** Notable increases in throughput and overall output quality, attributed to streamlined processes and automation.

**Reduction in downtime -** Predictive maintenance via digital twins led to fewer unplanned stoppages, translating into higher equipment availability and reduced operational costs.

**Enhanced supply chain coordination -** Real-time data access enabled faster, data-driven decisions, resulting in more reliable order fulfillment and inventory management.

These improvements exemplify the impact of Lean 4.0 strategies, where scalable automation and integrated digital technologies support lean, responsive and high-performance factory operations.

## Challenges

Lean 4.0 represents the convergence of traditional Lean tools such as VSM, Kaizen and Standard Work with Industry 4.0 technologies like IoT, AI and Edge computing. While the transformation is promising, there are challenges associated with its adoption and industrialization –



### People/Workforce

- Lack of skilled personnel to drive digital technologies at early stages
- Fear of job displacement or unfamiliarity with digital tools
- Leadership commitment and dedication are paramount for success



### Process

- Lack of standardization across workflows and complex processes
- Legacy equipment and data sources that are ill-equipped to communicate with IoT platforms require significant capital investment



### Technology

- Integration complexity – Harmonizing data sources, legacy systems and workflows can be challenging
- Digital infrastructure readiness can be time-consuming and introduce cyber risks.

The challenge is balancing Lean's simplicity and human-centric approach with I4.0's digital complexity, ensuring technological advancements and not compromising Lean principles.



# What lies ahead ...

## Lean 5.0

Industry 5.0 represents the upcoming industrial revolution, focusing on seamless collaboration between humans and technology to enhance sustainability and social well-being, with AI at the forefront, driving innovations and intelligence. The next-gen Lean (Lean 5.0), built on the synergy between Lean 4.0 and human-centric paradigms of Industry 5.0, will focus on human-centric values, sustainability and ethical design, aligning with Industry 5.0's broader goals. The emergence of human-centric Lean shall harmonize human-machine collaboration, leveraging digital tools at its core. Further, the waste dimension of Lean will be enriched with sustainability, adding energy waste and carbon footprints, among others, as new KPIs.

It will nurture Digital Lean, which augments real-time visibility into the Lean charter and enables adaptive takt time, among others, driving agility in operations. As mass personalization takes center stage, Lean 5.0 shall navigate the values of customization without waste through flexible automation and modular production.

## LeAI (Lean augmented by AI)

The fusion of Lean principles (waste elimination, flow, value creation) with AI-driven sensing, prediction, and decision-making will usher in a new era in Lean manufacturing. AI represents a new advancement in Lean practices, supercharging traditional Lean principles by shifting from reactive improvements to prescriptive and prognostic optimization. This leads to operations that are autonomous, self-efficient, self-reliable, smarter than ever and more adaptable to surroundings.

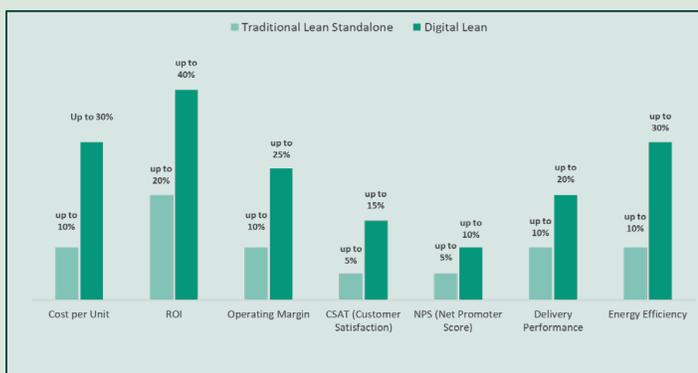
AI-powered continuous improvement leverages AI/ML to proactively identify opportunities, automate root cause analysis, and accelerate PDCA cycles. Dynamic value stream optimization leverages AI to analyze data and drive ongoing improvements in flow, inventory, and scheduling across the value chain. Use cases leveraging AI, such as predictive analysis, can eliminate waste; intelligent quality control with computer vision can deliver zero-defect processes; demand forecasting and inventory optimization can ensure just-in-time inventory; and process optimization, driving optimal takt time, among others, heralding a new era in the lifetime of Lean.

## Conclusion

Lean 4.0 delivers significant improvements in operational excellence by combining the well-known principles of traditional Lean with the advanced capabilities of Industry 4.0. With increasing competition and an upsurge in agile-driven markets, it is imperative to engage manufacturing practices that promise unconventional process optimization, embracing dynamic, data-driven decision-making and predictive analytics.

By combining IoT, AI, and digital twins with Lean methodologies, manufacturers can achieve greater agility and resilience driven by market sentiment. Lean 4.0 amplifies Lean principles, resulting in 2–3x improvements in most KPIs compared to traditional Lean. The biggest jumps are seen in cost per unit and energy efficiency.

Lean 4.0 is more than an incremental improvement - it is a strategic necessity for manufacturers seeking success in today's volatile, highly competitive and digitally integrated marketplace.



Graph 3: Enterprise benefits of Lean 4.0 over Traditional Lean

## Abbreviations

| Abbreviations | Description   |
|---------------|---|
| Kaizen        | Continuous improvement  |
| SMED          | Single Minute Exchange of Dies  |
| MUDA          | Originated from the Toyota Production System, which means Waste   |
| MURA          | Originated from the Toyota Production System, which means unevenness  |
| MURI          | Originated from the Toyota Production System, which means overburden  |
| VSM           | Value Stream mapping  |
| Kanban        | The Japanese word means card signal, a visual work management system  |
| 5S            | It refers to a workplace organization methodology that aims to create a clean, efficient, and safe work environment   |
| Poka-yoke     | Mistake proofing  |
| IoT           | Internet of Things  |
| AI/ML         | Artificial Intelligence/ Machine Learning   |
| JIT           | Just In Time  |
| CMO           | Current Mode of Operations  |
| PDCA          | The Plan-Do-Check-Act (PDCA) cycle is a four-step management method used for the control and continual improvement of processes and products introduced by Deming |

# References

1. [Toyota Production System - Wikipedia](#)
2. [Lean and Six Sigma Services Market Size, Consumer Insights & Forecast 2033](#)
3. [DIGITAL LEAN: A GUIDE TO MANUFACTURING EXCELLENCE](#)
4. [Lean 4.0 – The Convergence of Lean Thinking and Digital Tools](#)
5. [Implementing Lean 4.0 in Pharmaceuticals – Emerald Publishing](#)
6. [Lean Leadership 4.0 framework: a case study in an automotive company | Benchmarking: An International Journal | Emerald Publishing](#)

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