LTIMindtree

whitepaper

Transforming High-Tech Semiconductor Manufacturing:

A Comprehensive Industry 4.0 Assessment Framework for Enhanced Efficiency and Growth

Future businesses will heavily rely on semiconductors due to AI, IoT, and EV proliferation. Aligning with Industry 4.0, this paper introduces an assessment framework addressing semiconductor complexities and future possibilities, pivotal for process streamlining and evolution. Implementation of this framework, will help businesses create a strategic roadmap to achieve tangible benefits like

Reduce of technical debt by rationalizing the existing manufacturing IT/OT landscape

Improve operational efficiency as a result of simplification of the IT/OT landscape

Enhance and accelerate adaptability to new capabilities with simplified architecture

Introduction

In an era characterized by technological innovation and interconnectedness, there is no doubt that future businesses will run primarily on semiconductors. A significant percentage of demand for them is rooted in the proliferation of artificial intelligence (AI)-based business models, the increasing number of connected devices on the Internet of Things (IoT), and the growing demand for electric vehicles (EVs) (as per insights from Mckinsey, the global semiconductor industry is set for a decade of growth, with revenues estimated to climb to $1 trillion by 2030).

Meanwhile, semiconductor companies are also dealing with the complex requirements of Industry 4.0 players. They have to adapt their own products to the realities of smart factories. The technological trends are moving towards intelligent and energy-saving products, integrated security functions, and energy harvesting abilities.

Cyclical sales of computers and smartphones no longer dominate the semiconductor industry. As more advanced products enter the market, there is a need for innovative chipsets that require shorter lead times and higher throughput. Global companies also need energy-efficient and completely autonomous systems that can be integrated into existing structures on a plug-and-play basis. This is where Industry 4.0 tech plays a critical role. Semiconductor manufacturing has to be evaluated and streamlined in terms of product development, process automation, field servicing, and supply chain management.

This paper describes an assessment framework for generic semiconductor businesses wherein factories or manufacturing sites are assessed on the parameters of their current state, the future state of possibilities, the justification of those future states of options, and the functional capabilities that drive those possibilities. The scope of assessment dimensions includes but is not limited to product engineering, manufacturing schedules, energy management, inventory management, material dispatch, facilities management logistics, and product quality analysis.

Business Assessment Framework Overview

As the semiconductor industry makes efforts to meet rising demand, enterprises want to identify the best opportunities to increase current investments' potential and proactively predict the investments required to meet future demand. LTIMindtree has built a business assessment framework that blends traditional semiconductor Manufacturing standards and is an amalgamation of the Industry 4.0 model. This framework encompasses more than 50+ assessment points categorized across manufacturing processes, engineering, maintenance, and supply chain – these can be scored on six dimensions:

1. **Manual:** Operator and process-dependent operation
2. **Business Adhoc:** Working around as per business priorities
3. **Business Reactive:** Corrective actions based on business impact with short time vision
4. **Business Active:** Corrective actions based on continuous business impact analysis
5. **Business Predictive:** Corrective actions based on business impact predictions
6. **Autonomous:** Automated corrective actions based on business impact predictability

The framework is backed by LTIMindtree's extensive experience partnering with global semiconductor manufacturers and our proprietary tools and accelerators. It enables site and factory stakeholders to evaluate and benchmark the site business KPIs against the industry, and outline means to enhance business KPIs per site priorities.

Components of the Framework:

This comprehensive framework encompasses substrate manufacturing, Wafer Fab Manufacturing, and Back end operations (Assembly, Test, final test & Module house), significantly impacting business KPIs. It spans multiple facets—from Demand Forecasting to Equipment and Lot Management, Production Quality, Logistics, and beyond.

50+ Functional Dimensions:

These functional capabilities break down into sub-functional components, enabling detailed assessments of manufacturing facilities based on a scoring matrix.

5+ Scoring Matrix:

Assessing component scores reveals functional maturity gaps, highlighting areas for improvement aligned with customer priorities and investments necessary for enhancing respective business KPIs.

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Supply Chain Management	Manufacturing Operations	Engineering & Maintenance
Procurement Material | Vendor selection | Vendor management | GR | Inspection | Stocking | Location Tracking | Shelf Life	**Manufacturing** Engineering | Scheduling | Dispatching | Lot | Carrier | Batch | Equipment | Recipe | NPWT | APC |Maintenance | Reporting | Raw stock | FG & Shipment	**Product Engineering** NPI Release Management | Closed Loop manufacturing | Design to Manufacturing | NPI Order visibility | Product Bom Revisions | Experiment Management
Inbound & Outbound logistics Vehicle and Material tracking | Route optimization | Realtime location tracking | Automated Dispatch & Routing | Material Serialization | Inspection & putaway	**Quality Control & Management** SPC | Metrology DC | Recipe Hold | Lot Hold & Release | Batch hold & release | Recipe Parameter tuning | FF / FB – R2R | Yield management	**Durables & Consumables** Durables Tracking | Durables Maintenance | Consumables tracking | Consumables monitoring & safe disposition | Consumables Issue & Receive | Shelf-life management | Auto replenish
Inventory management Material management | Quality checks | RM tracking | GI & GR | Inventory Level Management | Auto replenish | Material issue & receive |Inventory Audit Management	**Reporting** ANDON | Shift Book | Realtime OEE | Control Command Centre | Lot & Batch Genealogy | Die to Wafer Traceability| OCAPs | Cross Site bench marking | Business & Operational KPI standardization | Predictive & cognitive analytics	**Facility Management** Asset Tracking | Asset Maintenance | Energy Management | Geo Fencing | Building Automation | Controls monitoring | ESG | Environment Safety

0	1	2	3	4	5
Manual Operator & Process dependent operation	**Business Adhoc** Work arounds based on the business priorities	**Business Reactive** Corrective actions based on the business impact with short time vision	**Business Active** Corrective actions based on the continuous business impact analysis	**Business Predictive** Corrective actions based on the business impact prediction	**Autonomous** Automated Corrective actions based on the business impact predictability

Understanding the Business Landscape: Hi-Tech and Semiconductor Manufacturing

The global semiconductor market is witnessing meteoric growth due to widespread semiconductor usage in data processing, networking, automotive parts, and more. The imminent rise of AI- and IoT-driven systems will propel market growth, and demand for high-performing 5G-compatible devices will also shape the industry's trajectory. Semiconductors, pivotal to digitization, rank among the world's most traded commodities, surpassing oil and vehicles.

Moore's Law projects a doubling of microchip computing power every two years, with costs halving, yet it's nearing physical and economic thresholds. The semiconductor realm faces a transformative juncture where factors converge to redefine its landscape in 2024 and onward. Chips approach the 2nm threshold, transistors shrink to atomic sizes, and R&D costs strain even major chipmakers. Future breakthroughs might harness chiplets, 3D stacking, material science, and innovative lithography to bolster computing capabilities.

The Link between Technology, Quality, Capacity, and ROI

Navigating the intricate relationship between Technology, Quality, Capacity, and ROI in semiconductor manufacturing is vital. The supply chain – a linchpin in a manufacturer's production system – impacts the entire value chain, influencing technologies, product quality, and capacity. Despite recovery efforts from the 2023 chip shortage, challenges persist, including excess inventory and export restrictions on crucial manufacturing elements. LTIMindtree's assessment framework becomes critical in this landscape, offering a robust tool to benchmark existing capacity through functional automation.

In 2024, electronic supply chains anticipate further shifts with evolving technologies. To address immediate challenges, businesses must foster internal teams for transparent supply chain management, identifying risks and enabling swift responses. Technological advancements, particularly in edge computing and the growing synergy between AI and semiconductor technology, are poised to enhance system efficiency. As semiconductor devices grow more complex, cybersecurity in chip design becomes paramount, necessitating hardware architecture upgrades and advanced cryptographic techniques to safeguard sensitive data—areas where LTIMindtree's assessment framework proves instrumental.

Business Assessment Parameters

To ensure that their organization is ready to evolve in line with the expectations of the semiconductor Regulatory requirements are also essential and considerable during the modernization of core.

Process Evaluation

LTIMindtree's extensive experience in the semiconductor manufacturing value chain has culminated in a comprehensive process map, where each component is meticulously categorized into functional capabilities and sub-functions. Our tailored framework serves as a versatile diagnostic tool, guiding organizations through every stage, from current state assessment to critical use case identification. It visualizes existing footprint locations, establishes a baseline, and facilitates performance comparison against KPI dashboards and external industry benchmarks. LTIMindtree's manufacturing diagnostic solution, presented as a mobile assessment app, simplifies the evaluation of maturity levers across relevant dimensions. This user-friendly tool aids in defining levers aligned with identified opportunities, allowing organizations to quantify and visualize the manufacturing process's full potential through overall data collection and diagnostics.

Functional Capability Matrix Analysis

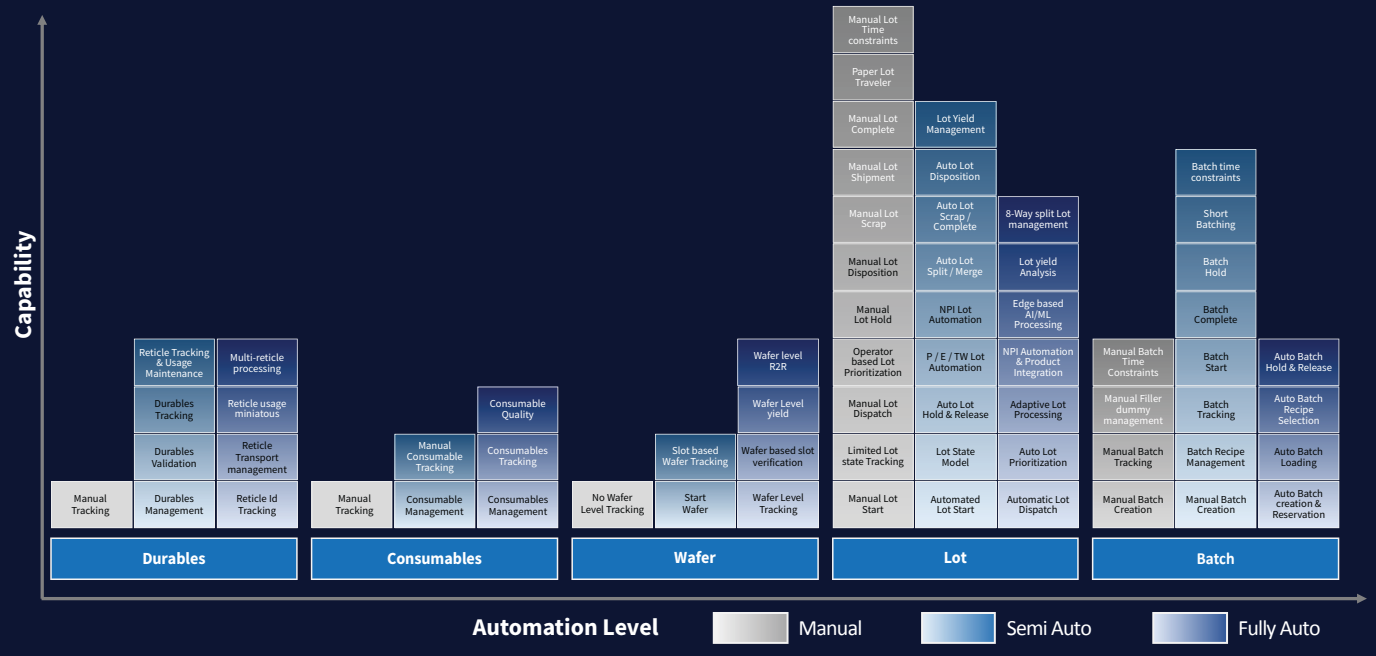
The functional capability matrix analysis provides a data-driven approach to check the existing functionalities of plant and team skills vis-à-vis the desired capabilities. It helps to identify the gaps to be closed.

For example, in semiconductor manufacturing, the digital readiness index for an application can be measured using functional capability matrix analysis.

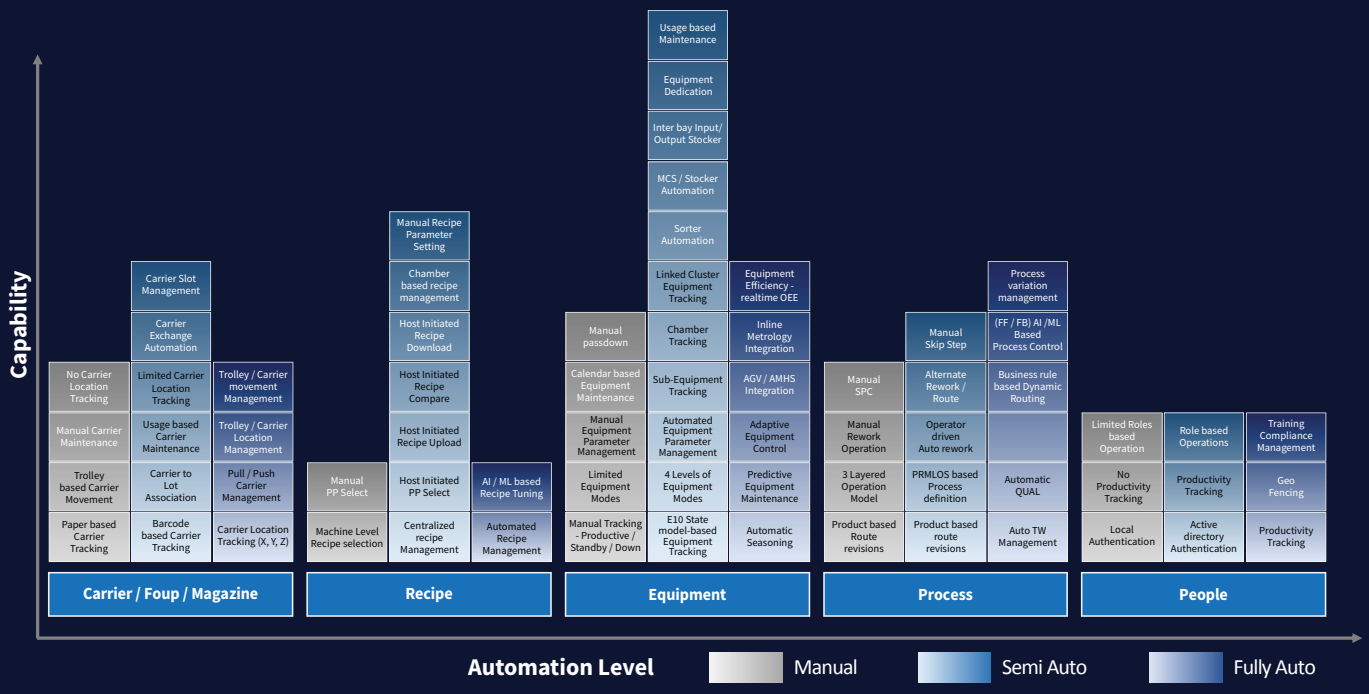
App Landscape Delivering Functional Index

The Purdue reference architecture for CIM (Computer Integrated Manufacturing), developed by ISA (International Society of Automation), serves as a conventional framework widely adopted by semiconductor manufacturers. This framework aligns with the integration principles of the ISA 95 standard. To enhance this architecture's efficiency, semiconductor equipment manufacturers for wafer fabs have standardized equipment communication interfaces using SECS/GEM (Semiconductor Equipment Communication Standard/Generic Equipment Model).

Semi.org has categorized each layer or level within the Purdue model according to specific functions, developing specifications accordingly. Applications grouped within each layer deliver distinct functionalities, and their maturity levels are assessed against a scoring matrix based on implemented functions and categories.



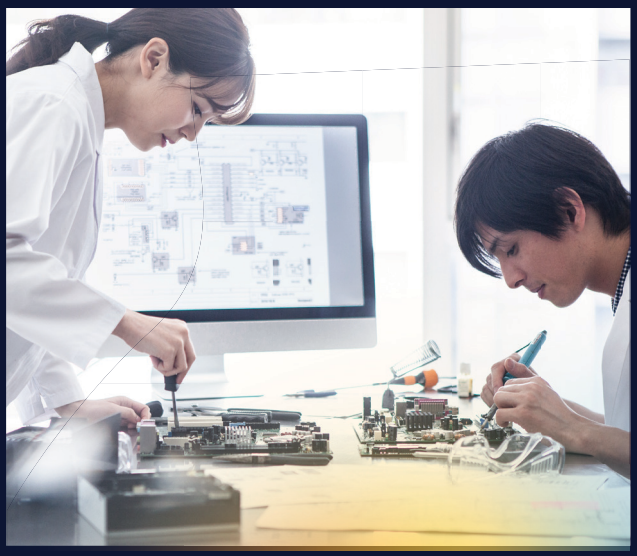
Example 1 – Functional capabilities broken into three levels of automation scorecard for material traceability



Example 2 – Functional capabilities broken into three levels of automation scorecard for operational control and traceability.

Operational & Business KPIs Evaluation

Operational and business KPIs hinge on the trifecta of people, processes, and systems. We advocate for intelligent systems supported by robust processes to mitigate human errors, while system intelligence ensures high availability through proactive monitoring and self-healing mechanisms. The efficacy of manufacturing plants, encompassing functions like facility management, supply chain management, engineering, manufacturing operations, logistics, and shipping, relies on specific functions offered by pertinent applications across engineering, enterprise, manufacturing, logistics, and shipping domains. The maturity of these applications significantly influences business KPIs.



LTIM's assessment framework zeroes in on appraising the maturity levels of these crucial business functions, recognizing their direct impact on overarching business KPIs.

Improvement Opportunities

Identifying Areas for Enhancement

As semiconductor players analyze their areas for improvement with a diagnostic solution, it is expected that IP reuse will still be a focus for future developments in the industry. However, the designs have now shifted to gaining market growth through customization. Rather than designing single, monolithic chips, semiconductor players must rely more on building chiplets. These specialized, modular chips can be combined for a complex, integrated system-on-chip (SoC). Chiplet-based designs have smaller, customizable building blocks. Using this approach, semiconductor manufacturers can help develop lighter hardware while reducing costs for consumers and enabling greater sustainability.

Business Process Automation

Automation in semiconductor manufacturing is about optimizing production using programmable logic controllers (PLCs), robots, and other industrial tools. It increases productivity, reduces production costs, and enhances product quality. A key benefit of automation is its ability to mitigate risks of human error while ensuring accuracy and consistency in results. Companies can use LTIMindtree's assessment framework to check the level of their process automation against industry standards and understand the areas of improvement.

Adoption of Industry 4.0 Capabilities

A semiconductor manufacturer should also conduct its maturity evaluation for Industry 4.0 capabilities, another area where our assessment framework helps. It enables users to check the maturity of their processes across the entire value chain with reference to design and engineering, order management, inventory management, substrate manufacturing, water fab manufacturing, backend manufacturing, product quality, supply chain management, and post-sale services.

Smart factories successfully adopting advanced Industry 4.0 practices typically score high on using autonomous solutions, AI/ML-enhanced systems, and digital twins.

Implementation Process for the Framework (Where to begin?)

1. **Discovery Phase:**

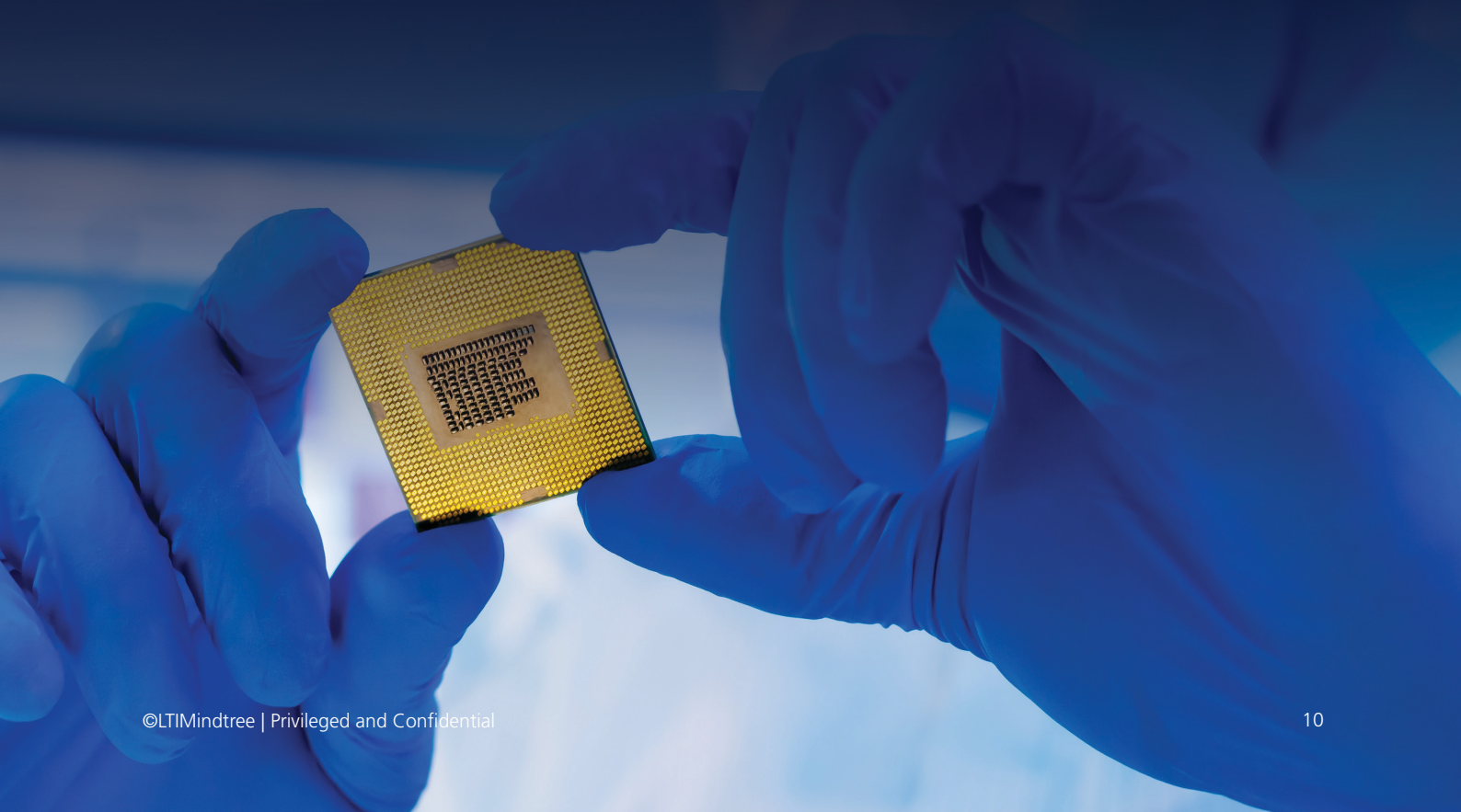
   During the discovery phase, the initial step involves a meticulous collection of application details within the manufacturing landscape. This encompasses a comprehensive approach to gathering data across various dimensions, including the application lifecycle, IT service management (ITSM) details, architectural specifics, and the intricate processes associated with each application.

2. **Analysis Phase:**

   Following the data collection, the analysis phase entails the processing and meticulous importation of this data into templates designed for evaluation. This process facilitates the generation of 4R App Quadrants and Spider Charts, providing a visual representation for a comprehensive understanding. The evaluation process involves carefully assessing each application, resulting in the documentation of recommendations aligned with their respective quadrants and charts.

3. **Recommendations Phase:**

   In the recommendations phase, a detailed explanation of various recommendation types is provided, explaining the diverse approaches for application enhancement. This phase prioritizes identifying low-hanging opportunities, ensuring swift and impactful improvements. Additionally, it involves the creation of a strategic medium to long-term roadmap, outlining the trajectory for sustained enhancements and innovation within the manufacturing landscape.



Framework Utilization and Benefits

Aimed at helping companies across the semiconductor value chain, LTIMindtree's Industry 4.0 assessment framework makes it easier to identify technology enhancements critical to scaling and sustaining Industry 4.0 manufacturing procedures. With a holistic assessment of semiconductor processes it also helps to build a roadmap for the adoption of Factory 4.0 initiatives.

Benefits of using the assessment framework

The Industry 4.0 assessment framework designed by LTIMindtree provides a structured model to evaluate the maturity level of production, quality checks, supply chain management, and other related processes in any semiconductor manufacturing environment. It helps them determine the best paths to a smart manufacturing journey and identify the steps that bring the highest returns on their investments.

Furthermore, this framework isn't limited to mere assessment; it is a catalyst for actionable change. It lays out comprehensive criteria for improvement, meticulously assigning scores across a maturity scale from 0 to 5. This structured approach aids in identifying areas ripe for enhancement, offering a roadmap for targeted and effective advancements within systems and processes, ensuring a tangible and strategic evolution toward Industry 4.0 excellence.

Real-world Success: Demonstrating Impact Through Semiconductor Industry Case Studies

LTIMindtree's framework has been deployed by several semiconductor players and other companies supplying components for digital systems. The following table briefly describes the domains they used it for and the KPIs on which a positive impact was recorded.

Client	Case	KPI impacted	Description
Leading Semicon Manufacturer in US	Global CIM baseline Mfg. IT Architecture	• Improve MTTR & MRBF & Technical debt reduction	• **Assessment** of 2 wafer fabs & 5 back-end facilities • **Analysis** of 600+ CIM apps and rationalization of 200+ Apps • Migration **strategy** for EI, RfID Integration, RTD implementation, Factory bus Architecture, MMS & SPC
Leading Semicon manufacturer in Germany	Global EI & RMS Migration	• Improve Factory automation & reduce process variations	• Assessment of Equipment (s) in shop floor & characterization of **72+ equipment types** • Development of **FOAK kind** of integration and successful deployment of equipment automation software • **Successful deployment** of RMS solution for each machine and implementation recipe find, recipe upload & download, recipe ascii and binary compare, golden recipe audit & revisions
Leading Semicon manufacturer in Netherlands	Selection of Global MDM, MMS & RMS vendor	• Improve machine uptime and reduce process variability	• **Assessment** of 3 Wafer Fabs in Europe and 4 back-end fabs in china, Malaysia and phillipines • Mfg IT landscape **analysis**, Equipment integration analysis, MES / MOM / SAP integration • Evaluated **6 vendors** and selected the rite fit vendor through scoring matrix

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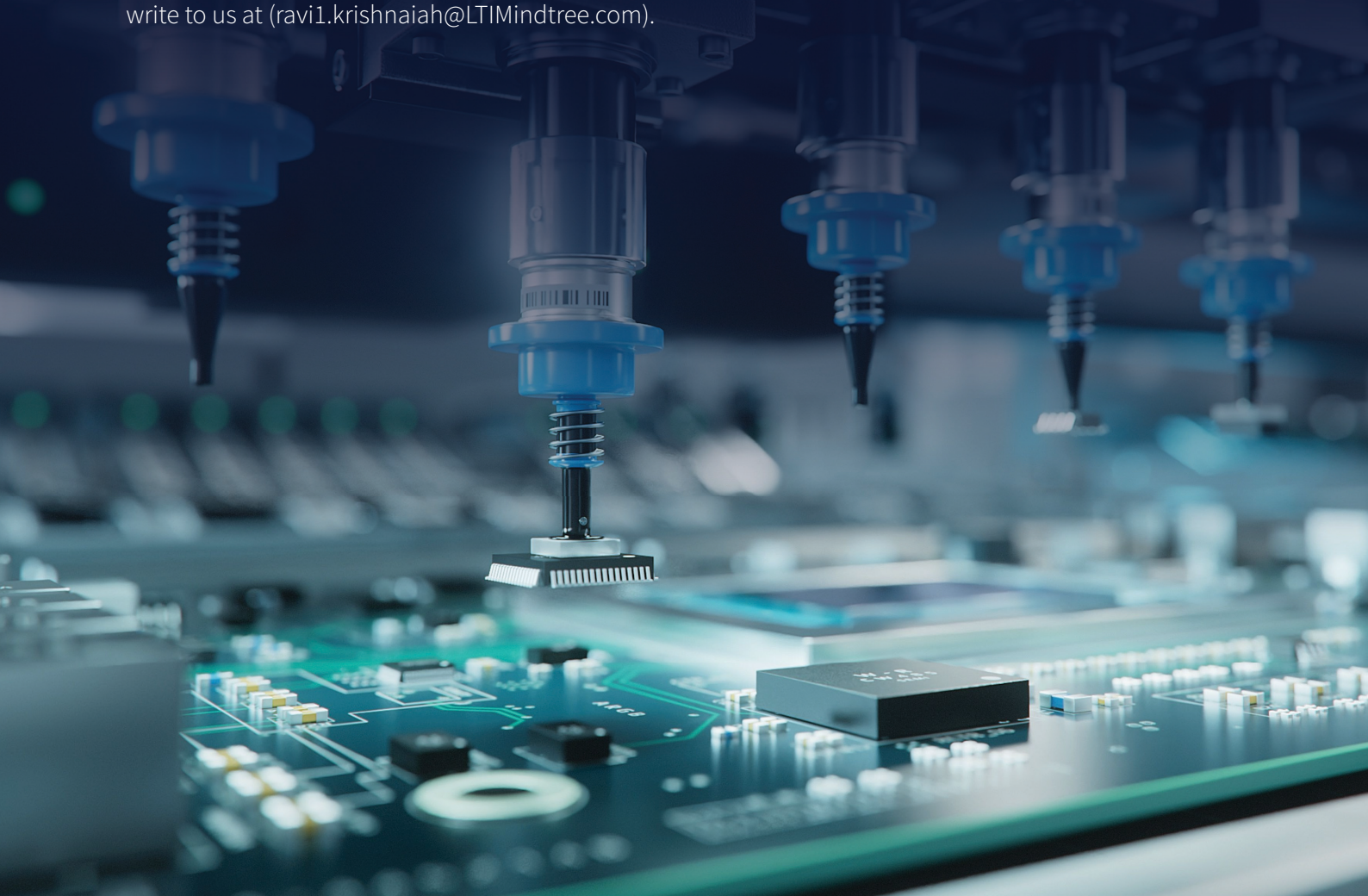
Empowering Semiconductor Evolution: The Impact of Our Framework

From the burgeoning demand driven by AI, IoT, and EVs to the evolution of semiconductor products within smart factories, there is no doubt that high-tech semiconductor manufacturing stands at a complex intersection with Industry 4.0. LTIMindtree's Industry 4.0 assessment framework offers a structured roadmap to traverse this dynamic journey. It offers a well-architected approach to evaluating and enhancing semiconductor processes and adopting Factory 4.0 initiatives. This framework isn't just about assessment; it's a catalyst for transformative change, pinpointing areas for improvement and guiding strategic evolution on a maturity scale from 0 to 5.

As we look ahead, the future of semiconductor manufacturing intertwines with the potential unlocked by this framework. It promises to revolutionize the industry by embracing technology enhancements critical for scaling and sustaining Industry 4.0 manufacturing procedures. Its roadmap paves the way for continued growth, innovation, and adaptability in an ever-evolving landscape.

For enterprises seeking to embark on a transformative journey within semiconductor manufacturing, leveraging the insights and guidance provided by LTIMindtree's Industry 4.0 assessment framework stands as a pivotal step. Explore its potential and chart a course toward sustainable growth and unparalleled excellence in the dynamic realm of semiconductor manufacturing;
write to us at (ravi1.krishnaiah@LTIMindtree.com).



Author

Ravi Krishnaiah

Principal Director, LTIMindtree

Ravi Krishnaiah is a Principal Director with the Customer Success Practice at LTIMindtree. He has over 25 years of experience in Manufacturing IT industry, providing strategic vision & roadmaps, leading high-performance consulting teams, preparing industry benchmarked assessment frameworks. His areas of expertise include Automotive and Aerospace Engineering, Electronics Industry, Life Sciences (Pharmaceuticals, Consumer & Medical Devices), Consumer Packaged goods (CPG) and High-Tech Semiconductor & Solar Industry.

About LTIMindtree

LTIMindtree is a global technology consulting and digital solutions company that enables enterprises across industries to reimagine business models, accelerate innovation, and maximize growth by harnessing digital technologies. As a digital transformation partner to more than 700 clients, LTIMindtree brings extensive domain and technology expertise to help drive superior competitive differentiation, customer experiences, and business outcomes in a converging world. Powered by 81,000+ talented and entrepreneurial professionals across more than 30 countries, LTIMindtree — a Larsen & Toubro Group company — combines the industry-acclaimed strengths of erstwhile Larsen and Toubro Infotech and Mindtree in solving the most complex business challenges and delivering transformation at scale. For more information, please visit **https://www.ltimindtree.com/.**