

A Vision 2030 Roadmap for Smart Connected Factories Using IoT and Advanced Automation in Saudi Arabia

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Abstract- Smart connected factories are becoming a practical pathway for Saudi Arabia to translate Vision 2030 industrial ambitions into measurable productivity, quality, sustainability, and localization outcomes. This review develops a Vision 2030 roadmap for factories that combine Industrial Internet of Things (IIoT), advanced automation, edge computing, artificial intelligence, digital twins, robotics, cybersecurity, and human-centred skills development. The study synthesizes peer reviewed literature published between 2020 and 2025, official Saudi industrial transformation priorities, and the technology-adoption logic reflected in contemporary Springer proceedings on technology, sustainability, and IoT-oriented innovation. The aim is not to propose a single vendor solution, but to frame a staged transformation model that Saudi manufacturers, industrial policymakers, and technology partners can adapt according to sector maturity and operational risk. The review shows that smart connected factories require four connected layers: a secure physical layer of sensors, controllers, robots, and energy meters; a resilient connectivity layer based on industrial protocols and private wireless networks; an intelligence layer that transforms raw data into digital twins, anomaly detection, scheduling, and predictive maintenance; and a governance layer that links operational decisions to Vision 2030 indicators such as non-oil industrial growth, high-quality jobs, export competitiveness, and resource efficiency. The proposed roadmap begins with readiness diagnosis and data governance, progresses through connected assets and automation pilots, moves into analytics-driven optimization, and culminates in scaled autonomous production ecosystems. The review contributes a structured methodology, two conceptual models, and an implementation matrix for smart factory modernization in Saudi Arabia.

Keywords- Saudi Vision 2030, Smart Factories, Industrial Internet of Things, Advanced Automation, Digital Twins, Predictive Maintenance, Cybersecurity, Industry 4.0, Saudi Manufacturing.

I. INTRODUCTION

Saudi Arabia's industrial transformation is entering a decisive stage in which digital technology is no longer treated as a support function, but as a foundation for competitiveness, resilience, and sustainable growth. Vision 2030 positions industrial development as a core route to diversify the economy, expand non-oil exports, create skilled employment, and localize strategic value chains.

In this setting, smart connected factories offer a powerful operational model because they join physical production assets with real-time data, automated control, advanced analytics, and decision systems. A smart factory can sense the condition of machines, materials, workers, products, utilities, and logistics flows; it can then interpret these signals through algorithms and convert them into actions that improve throughput, quality, safety, and energy performance (Büchi et al., 2020; Javaid et al., 2021).

For Saudi Arabia, the opportunity is especially important because many sectors targeted by industrial policy, including chemicals, food processing, mining, metals, construction materials, pharmaceuticals, logistics equipment, and high-tech manufacturing, depend on reliable production systems and continuous quality improvement.

The Kingdom has already signalled this direction through industrial modernization programs that encourage factories to move from labour-intensive and fragmented production toward operational efficiency, automation, and advanced industrial practices.

The policy logic is consistent with international Industry 4.0 research, which argues that industrial value is created when connected machines, cyber-

physical systems, cloud and edge platforms, artificial intelligence, and robotics are integrated into a coherent production architecture rather than purchased as isolated tools (Folgado et al., 2024; Ghobakhloo, 2020).

This point is central for Saudi factories: the challenge is not simply installing sensors or robots, but developing the organizational ability to convert operational data into better planning, lower downtime, stable quality, and measurable sustainability.

Recent Saudi-focused technology literature also supports this integrated view. The attached Springer reference volume on creativity, technology, and sustainability emphasizes the alignment of technology adoption with Vision 2030 and the Sustainable Development Goals, with chapters addressing smart technology adoption, IoT security, sustainable infrastructure, artificial intelligence, and digital connectivity in the Saudi context.

Its smart-technology framework combines technology, organizational, and environmental factors, while its 6G roadmap links future connectivity to IoT, digital twins, smart cities, and industrial applications (Alabdali & Pileggi, 2025; Akkari, 2025). This review follows that model by treating smart connected factories as socio-technical systems: technical architecture, management commitment, cybersecurity, workforce skills, finance, regulation, and sustainability outcomes must be designed together.

The research problem addressed in this review is that many factories begin digital transformation with fragmented automation projects but lack a Vision 2030-aligned roadmap. Without a roadmap, plants may collect data without governance, automate low-value tasks, underinvest in cybersecurity, ignore workforce adoption, or fail to link factory indicators to national industrial objectives.

Therefore, this paper asks: how can Saudi factories use IoT and advanced automation to progress from basic digital readiness to connected, optimized, and sustainable smart operations? The paper answers this

question through a structured literature review and conceptual synthesis.

Its contribution is a staged roadmap, a reference architecture, and practical implementation tables that connect technology choices with productivity, quality, safety, sustainability, and human-capital objectives.

II. AIM AND OBJECTIVES OF THE STUDY

The aim of this review is to develop a Vision 2030 roadmap for smart connected factories in Saudi Arabia by synthesizing recent research on IIoT, advanced automation, digital twins, predictive maintenance, robotics, artificial intelligence, cybersecurity, and sustainable manufacturing.

The study focuses on factories rather than general smart-city or enterprise digitization because manufacturing transformation requires direct integration between operational technology, information technology, people, and physical production constraints.

The first objective is to identify the core technological building blocks required for smart connected factories, including sensing, connectivity, edge computing, cloud platforms, advanced automation, digital twins, robotics, and analytics. The second objective is to examine how these technologies affect productivity, quality, reliability, safety, and sustainability in manufacturing environments.

The third objective is to evaluate organizational and governance factors that shape adoption, including leadership support, investment planning, skills development, cybersecurity maturity, data ownership, and change management.

The fourth objective is to propose a staged roadmap that Saudi factories can use to move from readiness assessment to scaled autonomous operations. The fifth objective is to align factory-level transformation with Vision 2030 outcomes such as non-oil industrial growth, high-value employment, export competitiveness, resource efficiency, and technology localization.

These objectives are intentionally different from a purely technical review. A factory can purchase connected devices without becoming smart, and it can install automation without creating sustainable industrial value.

The review therefore treats technology as a means to achieve measurable operational and national outcomes. This approach follows contemporary adoption literature, which shows that technology performance depends on compatibility with processes, management readiness, user acceptance, infrastructure, policy context, and environmental pressures (Alabdali & Pileggi, 2025; Ghobakhloo, 2020).

III. REVIEW METHODOLOGY

This paper adopts a structured narrative review methodology suitable for a roadmap-oriented conceptual paper. A full meta-analysis was not appropriate because the topic combines engineering architectures, management adoption models, national policy documents, and sustainability indicators.

Instead, the review followed four steps. First, the scope was defined around smart connected factories, IIoT, automation, digital twins, predictive maintenance, robotics, artificial intelligence, cybersecurity, and Saudi industrial transformation. Second, literature from 2020 to 2025 was screened to prioritize recent peer reviewed studies, review papers, and official strategy sources.

Third, the selected material was coded into thematic clusters: technology architecture, operational performance, quality and maintenance, sustainability, cybersecurity, workforce capability, and Vision 2030 alignment. Fourth, the themes were synthesized into a roadmap and reference architecture.

The methodology is informed by three adoption perspectives often used in technology transformation studies. The Technology-Organization-Environment framework helps explain why factory adoption depends not only on technical usefulness but also on management support, resources, infrastructure, regulation, and market pressure.

The Diffusion of Innovation perspective explains why smart factory practices spread gradually through pilots, demonstrable benefits, compatibility, and reduced complexity.

The Technology Acceptance Model highlights the role of perceived usefulness and ease of use for engineers, operators, maintenance teams, and managers who must trust the system before relying on automated recommendations (Alabdali & Pileggi, 2025; Marcon et al., 2022).

These perspectives are particularly relevant in Saudi Arabia because factory transformation involves policy incentives, workforce localization, supplier ecosystems, and industrial-sector diversity.

To improve relevance, the review applied inclusion criteria. Sources had to address at least one of the following: Industry 4.0 manufacturing technologies, IIoT architecture, digital twins, predictive maintenance, smart quality, automation, cybersecurity, sustainable manufacturing, or Saudi industrial transformation. Publications before 2020 were avoided except where a concept was foundational; however, the reference list is kept within 2020-2025 to match the required review window.

Exclusion criteria removed papers that discussed consumer IoT without industrial relevance, generic artificial intelligence without manufacturing context, or strategy documents without connection to operational transformation. The synthesis was then organized around a practical question: what should a Saudi factory do first, second, third, and fourth to become connected, automated, secure, and sustainable?

IV. CONCEPTUAL FOUNDATION: SMART CONNECTED FACTORIES

A smart connected factory is a production environment where machines, control systems, enterprise platforms, products, workers, and supply-chain partners exchange data continuously to support faster and better decisions. Its central feature is not merely connectivity, but closed-loop learning.

Sensors capture process variables such as vibration, pressure, temperature, cycle time, tool wear, product dimensions, energy consumption, and environmental conditions. Edge devices filter and process time-sensitive data near the machine.

Cloud or hybrid platforms store historical data, train models, and integrate information from manufacturing execution systems, enterprise resource planning systems, laboratory systems, maintenance systems, and supplier portals. Algorithms detect anomalies, forecast failures, optimize schedules, recommend quality adjustments, and support energy management (Lee et al., 2020; Tao et al., 2022).

Industrial IoT is the nervous system of this model. It connects heterogeneous assets that were previously isolated, including legacy machines, programmable logic controllers, robots, automated guided vehicles, quality inspection devices, warehouses, and utility systems.

In Saudi factories, IIoT can be used to monitor equipment health in harsh environments, track material flows across large industrial zones, reduce unplanned downtime in continuous-process industries, and enhance traceability in regulated sectors such as food, pharmaceuticals, and chemicals. The value of IIoT increases when it is paired with advanced automation.

Automation converts insights into action by controlling motion, dosing, inspection, sorting, packaging, maintenance scheduling, and material handling. Advanced automation also includes collaborative robots, autonomous mobile robots, machine vision, adaptive process control, and AI-assisted human-machine interfaces (Frank et al., 2021; Javaid et al., 2021).

Digital twins provide a bridge between data and decision-making. A digital twin is a dynamic virtual representation of an asset, line, process, or factory that is updated through live and historical data. In manufacturing, twins help stimulate production changes before implementation, predict failure modes, compare actual performance with expected performance, and evaluate energy or quality trade-offs.

Predictive maintenance is one of the most mature use cases because it converts machine signals into early warnings, reducing emergency repairs and spare-parts waste (Chen et al., 2025; Kaur et al., 2025).

Smart quality is another high-value use case because machine vision and statistical learning can detect defects earlier than manual inspection and identify process parameters that cause variation.

However, connectivity also expands cyber risk. The same networks that improve visibility can expose operational technology to unauthorized access, ransomware, data manipulation, and safety hazards.

The attached Springer reference discusses IoT security and privacy challenges, emphasizing encryption, access control, patching, strong credentials, secure configuration, and user awareness (El-Taj et al., 2025).

For factories, cybersecurity must be embedded in architecture from the start through network segmentation, zero-trust access, secure remote maintenance, asset inventory, vulnerability management, incident response, and alignment with Saudi cybersecurity requirements. A smart factory without cyber resilience is not a sustainable factory.

Human capability remains equally important. Smart factories change the role of operators from repetitive manual execution to data-informed supervision, exception handling, maintenance planning, and continuous improvement. Engineers need skills in automation, analytics, industrial networks, cybersecurity, and process optimization.

Managers need the ability to evaluate digital investments through operational value rather than technology novelty. Vision 2030 alignment therefore requires a human-centred model that creates quality jobs for Saudi talent and supports partnerships among factories, universities, technical institutes, and technology vendors.

V. VISION 2030 ALIGNMENT AND SAUDI INDUSTRIAL PRIORITIES

Vision 2030 gives smart connected factories a national purpose beyond internal efficiency. The National Industrial Strategy seeks to increase industrial contribution to gross domestic product, develop local content, strengthen non-oil exports, attract quality investments, and build competitive industrial clusters.

Smart factories support these outcomes because they improve consistency, speed, traceability, and cost control, which are necessary for export-oriented manufacturing and participation in global value chains. They also make factories more attractive for strategic partnerships because international companies increasingly expect digital traceability, environmental reporting, and production flexibility.

Saudi Arabia's Future Factories direction is especially relevant. The program aims to shift thousands of factories from dependence on low-skilled labour toward operational efficiency, automation, and advanced industrial solutions.

For existing factories, this means modernization without disrupting production. For new factories, it means designing digital readiness from the beginning, including sensorized assets, integrated control systems, energy monitoring, cybersecurity, data governance, and scalable automation.

This dual path is important because the Saudi industrial base contains both large capital-intensive plants and small or medium manufacturers that require affordable staged adoption.

A Vision 2030 roadmap should therefore balance ambition with practicality. The first national-level benefit is productivity. Connected operations increase overall equipment effectiveness by reducing stoppages, improving line balance, and accelerating root-cause analysis. The second benefit is quality.

Inline inspection, traceability, and analytics reduce scrap, rework, warranty losses, and customer complaints. The third benefit is sustainability. Smart meters, energy analytics, process optimization, and

predictive maintenance reduce energy consumption, water use, emissions, and waste. The fourth benefit is resilience.

Digital visibility supports supply-chain coordination, inventory optimization, and faster response to disruption. The fifth benefit is talent development. Automation should reduce low-value repetitive work while creating roles in robotics, data analysis, maintenance engineering, cybersecurity, and digital operations.

The Saudi context also creates specific design requirements. Industrial zones may contain large assets spread across wide areas, requiring robust connectivity and edge intelligence. Harsh environmental conditions require reliable sensors and protective enclosures. Some sectors, such as petrochemicals, metals, and mining, have high safety and continuity requirements, so automation must be validated carefully.

Small and medium factories may need shared service models, financing support, vendor-neutral standards, and training programs. These requirements suggest that smart factory transformation should be implemented through a roadmap rather than a single technology purchase.

VI. ROADMAP FOR IMPLEMENTATION

The proposed roadmap consists of four phases: diagnose, connect, optimize, and scale. The diagnose phase establishes readiness. Factories should begin by mapping assets, production flows, data sources, pain points, downtime causes, quality losses, energy consumption, cybersecurity gaps, and workforce skills.

This phase should produce a digital maturity score, a business case, and a prioritized use-case portfolio. High-value use cases often include condition monitoring for critical equipment, energy optimization for high-consumption lines, machine vision for quality control, digital work instructions, and automated material tracking. The output should not be a generic transformation statement; it should be a sequenced plan with owners, budgets, risks, and measurable indicators.

The connect phase builds the data foundation. Machines and utilities should be connected through industrial protocols, gateways, and secure networks.

Legacy equipment can be retrofitted using non-invasive sensors where full controller integration is not feasible. Edge computing should be used when low latency, local reliability, or data filtering is required.

Data governance must define naming standards, ownership, quality rules, retention, cybersecurity classifications, and integration with enterprise systems. This phase should also include operator dashboards that provide immediate visibility into downtime, throughput, quality, energy, and safety. Early wins are important because they create trust and encourage adoption.

The optimize phase uses analytics and automation to improve decisions. Predictive maintenance models can identify abnormal vibration, temperature, current, or pressure patterns before failure. Scheduling algorithms can reduce changeover losses and balance constraints. Machine vision can classify defects and feed results back to process parameters.

Digital twins can simulate bottlenecks, energy use, and production scenarios. Advanced process control can stabilize variables and reduce variability. These applications should be governed by model monitoring, human override rules, validation protocols, and cybersecurity review. The purpose is not to remove human judgment, but to strengthen it with reliable evidence.

The scale phase expands from pilots to enterprise and ecosystem integration. Successful use cases should be standardized across lines, plants, and suppliers. Factories should integrate production data with procurement, inventory, maintenance, logistics, quality, finance, and customer systems. Sustainability dashboards should connect factory energy, water, waste, and emissions indicators to corporate and national reporting.

Training academies and certification pathways should support Saudi talent in automation and digital operations. The final maturity stage is an adaptive

factory network where machines, people, and supply-chain partners coordinate through shared data and trusted governance.

Figure 1 presents the roadmap visually. It highlights that transformation begins with diagnosis and ends with scaled, autonomous, sustainable operations. The phases are sequential but iterative: a factory may return to diagnosis after each pilot, refine data standards, and upgrade skills as use cases mature.



Figure 1. Vision 2030 phased roadmap for smart connected factories in Saudi Arabia.

VII. TECHNOLOGY ARCHITECTURE FOR SAUDI SMART FACTORIES

The reference architecture for Saudi smart connected factories should be layered to avoid fragmented implementation. The physical layer includes machines, robots, programmable logic controllers, sensors, meters, conveyors, inspection stations, tools, environmental systems, and worker interfaces.

This layer must be reliable, maintainable, and safe because it directly affects production. The connectivity layer includes industrial Ethernet, OPC UA, MQTT, private 5G, Wi-Fi 6, low-power sensors, edge gateways, and secure remote access.

The intelligence layer includes manufacturing execution systems, data platforms, digital twins, AI models, quality analytics, maintenance systems, and optimization engines. The decision layer includes dashboards, alerts, automated workflows, sustainability reports, and management control towers.

This architecture should be hybrid rather than purely cloud-based. Some production decisions require millisecond response times and must remain at the edge or controller level. Other decisions, such as enterprise benchmarking, cross-factory learning, long-term maintenance models, and supplier analytics, can use cloud platforms.

Hybrid design also helps address data residency, cybersecurity, and operational continuity. Saudi factories should avoid technology lock-in by using interoperable standards and modular architectures. Vendor-specific solutions may be useful, but core data models, asset hierarchies, and integration rules should remain under factory governance.

Advanced automation should be selected according to process value. Collaborative robots may fit assembly, packaging, inspection, and repetitive handling. Autonomous mobile robots may support warehouse and line-side logistics. Machine vision can improve inspection and traceability.

Automated process control can benefit continuous operations where small deviations create large quality or energy losses. Digital work instructions and augmented reality can support maintenance and training. The correct automation strategy is therefore use-case-driven, not technology-driven.

Figure 2 shows the architecture as a closed learning loop. Physical operations generate data; connectivity moves data securely; intelligence converts data into predictions and recommendations; decision systems trigger action; and outcomes return to improve models. This loop is the practical meaning of a smart factory.



Figure 2. Edge-to-cloud smart factory architecture with a continuous learning loop.

VIII. DISCUSSION: BENEFITS, RISKS, AND GOVERNANCE

The benefits of smart connected factories are substantial, but they depend on governance. Productivity gains arise when downtime, speed losses, and bottlenecks are measured accurately and acted upon. Quality gains arise when inspection data is connected to process causes rather than stored separately.

Sustainability gains arise when energy and material indicators are linked to production planning and maintenance. Workforce gains arise when employees are trained to use digital systems and participate in improvement rather than being treated as passive recipients of automation.

The main risks are fragmentation, cybersecurity weakness, unclear data ownership, skills shortages, unrealistic return-on-investment expectations, and resistance to change. Fragmentation occurs when departments purchase separate tools that cannot exchange data.

Cybersecurity weakness occurs when operational networks are connected without segmentation, patching, monitoring, or access control. Data ownership problems occur when vendors control critical operating data or when internal teams cannot agree on definitions. Skills shortages occur when factories install technology faster than they develop people.

These risks can be reduced through governance boards, standard architectures, cybersecurity-by-design, vendor-neutral procurement, and staged implementation.

A practical governance model should include five mechanisms. First, each use case should have an executive sponsor, operational owner, technology owner, cybersecurity reviewer, and financial baseline. Second, factories should maintain a live asset and data inventory.

Third, model performance should be monitored, especially for predictive maintenance and quality algorithms. Fourth, employees should receive role-based training and be involved in interface design. Fifth, sustainability and Vision 2030 indicators should be reviewed with the same seriousness as cost and output indicators. This ensures that smart factory transformation supports national priorities rather than narrow technical experimentation.

The review also shows that Saudi Arabia can benefit from cluster-based learning. Industrial cities, economic zones, universities, and technology hubs can share reference architectures, training models, cybersecurity playbooks, and benchmarking methods. Smaller factories may adopt smart-factory-as-a-service models, shared testing labs, and government-supported maturity assessments. Large factories can act as anchor adopters by localizing supplier ecosystems and demonstrating advanced use cases.

IX. PROPOSED FRAMEWORK AND TABLES

Table 1 summarizes the main review themes and their implications for Saudi factories. Table 2 converts the roadmap into practical actions, indicators, and expected Vision 2030 contributions. Together, the tables show that smart factories should be evaluated across productivity, quality, sustainability, resilience, and talent outcomes.

A factory that improves output but ignores cybersecurity or workforce capability remains incomplete. A factory that installs sensors but lacks data governance will struggle to scale. A factory that automates without energy and waste indicators misses a key Vision 2030 opportunity.

The proposed framework can be used by plant managers, consultants, policymakers, and technology providers. Plant managers can use it to select high-value pilots. Consultants can use it to structure maturity assessments.

Policymakers can use it to design incentives that reward measurable transformation rather than equipment purchases alone. Technology providers can use it to align solutions with industrial outcomes. Researchers can use it to develop empirical studies that test the relationship between IIoT maturity, automation intensity, cybersecurity readiness, workforce skills, and factory performance in Saudi Arabia.

Table 1. Review themes and implications for smart connected factories.

Theme	Key finding from 2020-2025 literature	Implication for Saudi factories
IIoT connectivity	Connected sensors and machines create the data layer for visibility, traceability, maintenance, and quality analytics.	Begin with critical assets, legacy-machine retrofits, secure gateways, and common asset naming standards.
Advanced automation	Robotics, machine vision, automated material handling, and adaptive control improve consistency and reduce repetitive work.	Select automation based on bottleneck value, safety risk, labour intensity, and quality impact.
Digital twins	Dynamic virtual models support simulation, predictive maintenance, and scenario testing before physical change.	Prioritize twins for critical equipment, high-energy processes, and constrained production lines.

Cybersecurity	IoT and OT connectivity expand attack surfaces and require security-by-design.	Apply segmentation, strong identity, patching, monitoring, incident response, and secure vendor access.
Sustainability	Smart meters and analytics link production decisions to energy, water, waste, and emissions performance.	Include green KPIs in factory dashboards and investment cases from the first phase.
Human capability	Adoption depends on operators, engineers, and managers trusting and using digital systems.	Build role-based training in automation, analytics, maintenance, cybersecurity, and continuous improvement.

Table 2. Implementation roadmap matrix aligned with Vision 2030 outcomes.

Roadmap phase	Main actions	Example indicators	Vision 2030 contribution
1. Diagnose	Assess maturity, map assets, identify pain points, rank use cases, and prepare business cases.	OEE baseline, downtime causes, scrap rate, energy intensity, skill gaps.	Creates evidence-based industrial modernization plans and avoids fragmented spending.
2. Connect	Install sensors, gateways, secure networks, dashboards, and data governance	Connected critical assets, data quality score, live downtime dashboard, cyber asset	Builds digital infrastructure for competitive and transparent manufacturing.

	standards.	inventory.	
3. Optimize	Deploy predictive maintenance, machine vision, digital twins, advanced scheduling, and energy analytics.	Downtime reduction, defect reduction, schedule adherence, energy per unit, maintenance lead time.	Improves productivity, quality, sustainability, and export readiness.
4. Scale	Standardize successful use cases across lines, plants, suppliers, and sustainability reporting.	Use-case replication rate, supplier integration, Saudi digital roles created, ESG reporting coverage.	Supports localization, quality jobs, resilient supply chains, and non-oil industrial growth.

X. CONCLUSION

This review developed a Vision 2030 roadmap for smart connected factories using IoT and advanced automation in Saudi Arabia. The central finding is that smart factory transformation must be staged, integrated, secure, and human-centred.

The roadmap begins with diagnosis, continues through connected assets and data governance, advances into analytics and automation, and scales into autonomous and sustainable factory networks. IIoT provides visibility, automation provides action, digital twins provide simulation and learning, cybersecurity provides trust, and workforce development provides long-term capability.

For Saudi Arabia, the strategic value of smart connected factories lies in their ability to translate national industrial ambition into measurable operational performance. They can increase productivity, improve quality, reduce downtime, optimize energy and resources, strengthen supply-

chain resilience, and create high-quality technical jobs. However, these outcomes are not automatic.

They require leadership commitment, interoperable architecture, disciplined data governance, cybersecurity-by-design, realistic investment sequencing, and continuous skills development.

Future research should move from conceptual roadmaps to empirical validation in Saudi factories. Useful studies could compare maturity levels across sectors, measure the return on predictive maintenance, evaluate cybersecurity readiness in operational technology, assess workforce acceptance of automation, and quantify sustainability gains from smart energy management. Such evidence would help policymakers and industrial leaders refine incentives, standards, and training programs.

By following a roadmap rather than isolated adoption, Saudi factories can become connected, automated, competitive, and sustainable contributors to Vision 2030.

The roadmap also has a practical role in investment governance. Saudi factories should translate each phase into a portfolio of business cases rather than one large transformation contract. Each business case should state the operational problem, baseline data, expected saving, payback period, cybersecurity controls, training requirement, and owner.

This discipline protects factories from technology fashion and helps management compare automation projects with conventional improvement options. It also helps lenders and government programs evaluate whether financial support will create measurable industrial value. In early phases, low-cost use cases such as energy sub-metering, condition monitoring, digital downtime logs, and electronic work instructions can create evidence and confidence.

In later phases, higher-complexity use cases such as digital twins, autonomous logistics, closed-loop quality control, and AI scheduling can be justified because the data foundation and workforce confidence are stronger.

A second practical implication is the need for interoperability. Saudi factories should not build disconnected islands of automation.

A robot cell, a machine-vision station, an energy dashboard, and a maintenance platform may all be useful, but their value is limited if they cannot exchange data with the manufacturing execution system, enterprise resource planning system, and quality system.

Interoperable standards, shared asset hierarchies, and documented interfaces should be part of procurement. This approach reduces vendor lock-in and supports localization because Saudi engineers and local technology partners can maintain, extend, and integrate systems over time. Interoperability also supports cybersecurity because assets, identities, network flows, and access points can be monitored consistently.

A third implication concerns workforce transition. Smart connected factories should be presented as a pathway to safer, more skilled, and more attractive industrial employment. Operators can move from manual recording to exception management, maintenance technicians can move from reactive repair to reliability analysis, and engineers can move from periodic reporting to real-time optimization.

Training should combine classroom learning, simulation, vendor certification, and supervised factory projects. This is especially important for Vision 2030 because industrial modernization should create quality jobs for Saudi nationals, not simply import technology. When employees understand why a system is useful, how data is protected, and how automation supports safety and quality, adoption becomes faster and resistance becomes lower.

Finally, the roadmap should be measured through a balanced scorecard. Financial indicators such as cost reduction and output growth should be joined with operational indicators such as OEE, mean time between failures, first-pass yield, schedule adherence, and inventory accuracy.

Sustainability indicators should include energy per unit, water intensity, waste rate, carbon intensity, and

maintenance-related spare-parts consumption. Human-capital indicators should include training hours, certified digital roles, Saudi technical employment, and employee participation in improvement projects.

Cybersecurity indicators should include asset inventory coverage, patch compliance, privileged access review, incident response testing, and secure remote-access use. This balanced measurement system keeps the transformation aligned with Vision 2030, because it connects factory performance with economic diversification, skills development, environmental efficiency, and resilience.

It also makes progress visible to executives, regulators, investors, and employees, turning smart manufacturing from an abstract ambition into a controlled national industrial capability. For policy makers, the same scorecard can identify sectors that need financing, standards, training, or shared testing facilities.

For factory leaders, it can show whether pilots are ready to scale or require redesign. For researchers, it creates comparable variables for future Saudi empirical studies. For technology providers, it clarifies that success will be judged by operational evidence, not by the novelty of devices alone.

This shared measurement logic is essential for building trust between industrial companies, public agencies, investors, technology vendors, and employees during long-term factory transformation programs and national industrial value chains.

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