Advancing Supply Chain Resilience in APEC Economies Through 5G Smart Manufacturing

APEC Policy Partnership on Science, Technology and Innovation

May 2026

Asia-Pacific
Economic Cooperation

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APEC Project: PPSTI 103 2024A

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APEC# 226-PP-01.4

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KEY ABBREVIATIONS

Abbreviations	Full Term
5G	Fifth-Generation Mobile Network
6G	Sixth-Generation Mobile Network
6G Forum	Korea 6G Forum
A*STAR	Agency for Science, Technology and Research
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AIoT	Artificial Intelligence of Things
AMR	Autonomous Mobile Robot
APEC	Asia-Pacific Economic Cooperation
AR/VR	Augmented Reality / Virtual Reality
Big Data	Big Data Analytics
BOI (Thailand)	Board of Investment
CAPEX	Capital Expenditure
CIER	Chung-Hua Institution for Economic Research
CORFO	Corporación de Fomento de la Producción
CSBC	CSBC Corporation
CT	Communication Technology
CTC	Itochu Techno-Solutions Corporation
CU	Centralized Unit
DEPA (Thailand)	Digital Economy Promotion Agency
DoIT (Chinese Taipei)	Department of Industrial Technology
DT	Digital Twin
DU	Distributed Unit
ESG	Environmental, Social, and Governance
GDP	Gross Domestic Product
IIoT	Industrial Internet of Things
IMDA (Singapore)	Infocomm Media Development Authority
ITRI	Industrial Technology Research Institute
Kominfo (Indonesia)	Ministry of Communication and Digital Affairs
MEC	Multi-access Edge Computing
MIC (Japan)	Ministry of Internal Affairs and Communications

MIC (Chinese Taipei)	Market Intelligence & Consulting Institute
MIRDC	Metal Industries Research & Development Centre
mmWave	Millimeter Wave
MODA (Chinese Taipei)	Ministry of Digital Affairs
MoI (Indonesia)	Ministry of Industry
MTC (Peru)	Ministry of Transport and Communications
MSIT (Korea)	Ministry of Science and ICT
NaaS	Network-as-a-Service
NBTC (Thailand)	National Broadcasting and Telecommunications Commission
NTW	National Taiwan University
NPN	Non-Public Network
OCSVM	One-Class Support Vector Machine
OEE	Overall Equipment Effectiveness
OPEX	Operational Expenditure
O-RAN / Open RAN	Open Radio Access Network
PCB	Printed Circuit Board
PdM	Predictive Maintenance
PIDI 4.0	Indonesia Industrial Digital Center 4.0
PPP	Public–Private Partnership
ROI	Return on Investment
RU	Radio Unit
SA	Standalone (5G Architecture)
SUBTEL (Chile)	Subsecretaría de Telecomunicaciones
TKDN	Domestic Component Level
UPF	User Plane Function
Wi-Fi 6	Wi-Fi Sixth Generation
XGMF	XG Mobile Promotion Forum
Zero Trust	Zero-Trust Security Architecture

1. Introduction

1.1 Global Context: Manufacturing Transformation in an Era of Uncertainty

The global manufacturing landscape has entered a period of accelerated transformation driven by digitalization, geopolitical realignment, and sustainability imperatives. Over the past decade, globalization enabled highly optimized, efficiency-driven supply chains characterized by just-in-time production and extensive cross-border specialization. While these models delivered significant cost and productivity advantages, they also embedded structural vulnerabilities that became increasingly evident under systemic stress.

The COVID-19 pandemic exposed critical weaknesses in global supply chains, including overconcentration of production capacity, dependence on single-source suppliers, and limited agility in responding to sudden demand fluctuations and logistics disruptions. Factory shutdowns, labor shortages, transportation bottlenecks, and shortages of key components, most notably semiconductors, triggered cascading impacts across multiple industries, ranging from automotive and electronics to healthcare and food systems. These disruptions underscored the limitations of supply chain models that prioritize efficiency without sufficient resilience.

Simultaneously, geopolitical tensions, trade realignments, and evolving industrial policies are reshaping global production networks. Economies are increasingly reassessing supply chain strategies with heightened emphasis on security, diversification, and regionalization. In parallel, climate change and environmental pressures are accelerating the transition toward sustainable manufacturing practices, requiring reductions in carbon emissions, improvements in energy efficiency, and enhanced transparency across supply chains.

In the post-pandemic era, economies within the Asia-Pacific region have recognized the urgent need to strengthen supply chain resilience, security, and sustainability while continuing to pursue innovation and competitiveness. Balancing robustness with growth has become a defining challenge for policymakers, industry leaders, and technology stakeholders across APEC economies.

1.2 APEC's Strategic Role in Strengthening Supply Chain Resilience

The Asia-Pacific Economic Cooperation (APEC) has long served as a collaborative platform for addressing cross-border challenges through policy dialogue, technology cooperation, and capacity building. With its diverse membership encompassing advanced, emerging, and developing economies, APEC is uniquely positioned to promote inclusive and coordinated approaches to economic resilience and digital transformation.

In recent years, supply chain resilience has emerged as a central priority within the APEC agenda. Beyond reactive risk mitigation, APEC emphasizes proactive capability building—enabling economies to anticipate disruptions, adapt rapidly, and recover effectively. This forward-looking approach is particularly relevant in the Asia-Pacific region, where production and logistics networks are deeply interconnected and interdependent.

Within this context, smart manufacturing has gained recognition as a foundational enabler of resilient supply chains. By integrating digital technologies into manufacturing and logistics processes, smart manufacturing enhances visibility, flexibility, and responsiveness. These capabilities are essential for managing uncertainty and maintaining continuity across complex regional and global value chains.

1.3 Continuity and Evolution of the APEC Smart Manufacturing Agenda

The 2025 APEC Workshop on Smart Manufacturing, organized by the Industrial Technology Research Institute (ITRI) of Chinese Taipei, represents a continuation of APEC's multi-year strategic agenda—progressing from linkage (2022) and dialogue (2023) to advancement (2024). Each phase has contributed to building shared understanding, fostering trust, and identifying practical pathways for technology adoption among member economies.

The 2025 workshop marks a transition from conceptual exploration to deeper integration and implementation. It focuses on advancing the convergence of 5G-enabled smart manufacturing with artificial intelligence (AI), the Industrial Internet of Things (IIoT), edge computing, and data-driven decision-making. Rather than treating these technologies as isolated solutions, the workshop emphasizes their combined and systemic impact on manufacturing, logistics, and service ecosystems.

By building on previous discussions, the event seeks to translate strategic concepts into actionable frameworks. It highlights how advanced connectivity and intelligent systems can be deployed not only in large enterprises but also scaled to support small and medium-sized enterprises (SMEs), which constitute the backbone of many APEC economies.

1.4 Paradigm Shift in Supply Chains: From Efficiency to Intelligent Resilience

Supply chains across APEC economies are undergoing a paradigm shift from traditional linear, efficiency-oriented models toward intelligent, data-driven, and adaptive networks. This transformation reflects a growing recognition that efficiency alone is insufficient in an increasingly volatile and uncertain global environment.
Emerging technologies—particularly 5G-enabled smart manufacturing, IIoT, edge computing, and digital twins—are redefining industrial operations. High-speed, low-latency connectivity enables real-time communication among machines, sensors, and systems, supporting remote operations, predictive maintenance, and autonomous coordination. Digital twins provide virtual representations of physical assets and processes, allowing manufacturers to simulate scenarios, optimize performance, and anticipate failures before they occur.

These technological advancements enhance productivity and flexibility while significantly strengthening resilience. Real-time visibility across production and logistics networks enables earlier detection of disruptions and more informed decision-making. Predictive analytics shifts operational management from reactive responses to proactive risk mitigation. Moreover, digitalization contributes to sustainability objectives by optimizing resource utilization, reducing waste, and enabling more accurate measurement of environmental impacts.

1.5 Addressing Development Gaps Across APEC Economies

Despite rapid technological progress, disparities persist among APEC economies in terms of digital readiness, spectrum availability, workforce capabilities, and infrastructure maturity. Advanced economies such as Japan; Republic of Korea; and Chinese Taipei have already deployed private 5G networks, AI-driven factories, and integrated smart manufacturing ecosystems, supported by strong industrial bases and robust R&D capacities.

In contrast, many developing member economies face challenges related to spectrum access for private 5G, standardization, cybersecurity, and talent development. For SMEs, high upfront investment costs and uncertainty regarding returns on investment remain significant barriers. Without coordinated intervention, these disparities risk widening the digital divide and limiting the inclusive benefits of industrial transformation.

Bridging these gaps requires regional cooperation, policy harmonization, and targeted capacity-building initiatives. Through the APEC framework, economies can share best practices, align standards, and develop supportive environments that lower adoption barriers while ensuring that digital transformation benefits are broadly distributed.

1.6 Purpose and Significance of the 2025 APEC Workshop

The 2025 workshop serves as a milestone to consolidate previous achievements and foster cross-economy collaboration in deploying 5G-enabled smart manufacturing as a foundation for resilient and sustainable supply chains. It provides a platform for policymakers, industry practitioners, researchers, and technology providers to exchange insights, align strategies, and identify common challenges.

Through case studies, policy dialogues, and experience sharing, the workshop aims to identify actionable strategies that enable APEC economies to pursue inclusive digital transformation collectively. Emphasis is placed on practical implementation, scalability, and policy relevance to ensure that outcomes can be translated into tangible impacts across diverse economic contexts.

1.7 Technical Perspective: 5G as a Foundational Digital Infrastructure

From a technical perspective, 5G should be viewed not merely as a communication upgrade, but as a foundational digital infrastructure underpinning smart manufacturing and resilient supply chains. Compared with traditional wired Ethernet and Wi-Fi systems, 5G offers ultra-low latency, high reliability, massive connectivity, and network programmability, capabilities that address the stringent requirements of industrial environments.

Ultra-Reliable Low-Latency Communication (URLLC) enables millisecond-level response times, supporting wireless closed-loop control for precision manufacturing processes that previously relied exclusively on wired connections. Massive Machine-Type Communication (mMTC) facilitates dense sensor deployments, enabling comprehensive real-time monitoring of equipment, energy usage, environmental conditions, and logistics flows. Enhanced Mobile Broadband (eMBB) supports high-resolution imaging, augmented reality (AR), and remote expert assistance, expanding human-machine collaboration beyond physical constraints.

As 3GPP standards continue to evolve, the integration of 5G with Time-Sensitive Networking (TSN), industrial Ethernet, and future 6G technologies will further advance industrial connectivity convergence. These developments position 5G as a long-term enabler of industrial digital transformation rather than a short-term technological solution.

1.8 Policy Perspective: Governance, Coordination, and Capacity Building

From a policy perspective, the adoption of 5G smart manufacturing extends beyond technology deployment to encompass governance frameworks, regulatory coordination, and institutional capacity building. Effective policy environments are essential for reducing adoption barriers, scaling applications, and ensuring equitable outcomes.

Spectrum policy is a critical enabler of private 5G deployment. Several APEC economies have introduced dedicated or shared spectrum models to support non-public networks in industrial settings. For economies at earlier stages of exploration, sharing policy experiences through APEC can reduce experimentation costs and accelerate regulatory maturity.

Cybersecurity and data governance represent another key policy dimension. As industrial systems become increasingly interconnected, cybersecurity risks escalate from firm-level concerns to Economy-level and regional challenges. Policymakers must balance data protection with innovation, promote international standards, and foster trust in digital ecosystems.

Support for SMEs and workforce development is equally crucial. Compared with large enterprises, SMEs often lack the financial and technical resources required for advanced technology adoption. Policy tools such as pilot projects, testbeds, public–private partnerships, and skills training programs can lower entry barriers and support inclusive participation in smart manufacturing transformation.

As a regional cooperation platform, APEC plays a vital role in facilitating policy dialogue, standard alignment, and capacity building. By sharing experiences across economies at different stages of development, APEC helps promote scalable, transferable, and inclusive models of 5G-enabled smart manufacturing.

1.9 Concluding Remarks

The convergence of digitalization, sustainability imperatives, and geopolitical realignment has fundamentally reshaped the priorities of global manufacturing and supply chains. Within this evolving landscape, 5G-enabled smart manufacturing offers a powerful pathway for APEC economies to enhance resilience, competitiveness, and sustainability simultaneously.

The 2025 APEC Workshop on Smart Manufacturing provides a timely opportunity to consolidate knowledge, align policies, and strengthen collaboration across the region. By integrating technological innovation with thoughtful policy design, APEC economies can ensure that digital transformation translates into shared prosperity, industrial upgrading, and long-term resilience across the global supply chain ecosystem.

2. Analysis of Pre-Event Survey Results.

2.1 Chile

Chile stands as Latin America's most technologically advanced and digitally stable economy, consistently ranking first in innovation and digital governance across the region. This leadership has positioned the economy as a regional vanguard for technological transformation. At present, Chile's manufacturing sector—contributing roughly 10% of the economy's GDP—has entered a pivotal stage in its digital evolution, shifting from a historic dependence on mining and raw materials toward smart, high-value, and sustainable production systems that underpin economic diversification.

The sector's industrial base is broad, encompassing food processing, metal fabrication, chemicals, and precision engineering. In 2024, total industrial output reached USD 3.2 billion, with medium-term expansion expected as automation and digital technologies gain momentum. Automation now represents the central axis of Chile's manufacturing transformation. Rising labor costs, global supply chain restructuring, and sustainability imperatives have accelerated the adoption of Industry 4.0 solutions. Nearly half of manufacturing enterprises have implemented technologies such as IoT sensing, automated inspection, and machine learning-based quality control—signaling a decisive move from conceptual planning to operational deployment.

Driving this transition, CORFO's "Industria Avanzada" program serves as the cornerstone of Chile's industrial innovation ecosystem. It fosters pilot production lines, incentivizes R&D collaboration, and promotes cross-sector technology transfer—effectively bridging public policy with industrial modernization.

Chile's early leadership in 5G infrastructure further strengthens this digital foundation. With 5G already accounting for 30% of mobile connections, its deployment—enabled by transparent, non-profit spectrum auctions—has set a regional benchmark. The next policy phase (2026–2030) aims to deepen 5G integration into industrial applications, particularly within manufacturing, logistics, and remote operations.

However, systemic constraints persist. According to a SUBTEL survey, the integration of new technologies with legacy systems remains the foremost barrier to digital transition, revealing significant technical debt within aging industrial assets. Additional challenges include limited investment capacity and cybersecurity vulnerabilities, both of which hinder large-scale adoption of intelligent technologies. Current digital transformation efforts remain concentrated in foundational stages—automation, remote monitoring, and real-time analytics—falling short of the policy ambition for advanced smart manufacturing.

Looking ahead, the industry identifies 5G connectivity, automation, and AI/ML as the three critical enablers for the next five years. 5G, in particular, is viewed as transformative—empowering remote machinery control, predictive maintenance, and AI-driven anomaly detection—enhancing productivity, resilience, and supply chain visibility.

To accelerate this momentum, industry respondents emphasize the necessity of fiscal incentives, targeted policy support, and international collaboration. Technology transfer and knowledge sharing are recognized as essential to overcoming capability gaps and sustaining innovation diffusion.
On the workforce front, female participation in smart technology roles (currently 21–40%) signals both progress and untapped potential. The shift toward data-driven and remotely managed operations, enabled by 5G, is expected to create more inclusive opportunities, emphasizing analytical and leadership competencies over physical labor.

In sum, Chile is forging a modern industrial trajectory anchored in automation, digital infrastructure, and coordinated policy synergy. Its domestic strategy identifies 5G, AI, and automation as the pillars of industrial competitiveness and supply chain resilience. Yet, unlocking full potential will depend on overcoming structural bottlenecks—legacy integration, financial limitations—and deepening both domestic incentives and international technology partnerships to ensure Chile's continued ascent as a digital manufacturing leader in Latin America.

2.2 Indonesia

Indonesia’s commitment to 5G smart manufacturing is defined by the economy-wide Making Indonesia 4.0 (MI 4.0) roadmap, which aims to leverage technologies such as AI, IoT, and robotics to transform the manufacturing sector and position the economy among the world's top ten economies by 2030. The high throughput and low latency of 5G are crucial for realizing this ambition. Governance is structured through a dual mechanism involving the Ministry of Industry (MoI), which drives the industrial strategy and talent development via the PIDI 4.0 center, and the Ministry of Communication and Digital Affairs (Kominfo), which manages spectrum and regulatory enforcement. Policy deployment prioritizes seven key manufacturing sectors, with 5G rollouts specifically recommended for associated industrial zones.

Kominfo is strategically advancing Private 5G (P5G) networks, particularly utilizing millimeter-wave (mmWave) for dense industrial applications, despite the measured release pace of critical mid-band spectrum. A pivotal regulatory reform is the proposal for a new Spectrum Usage Fee (BHP) calculation tailored for P5G in industrial estates. This forward-thinking model substitutes economy-wide population metrics with the density of machines and human populations within the specific industrial area, thereby directly addressing industrial digitalization needs and reducing deployment cost Furthermore, Ministerial Decree KM No. 204/2025 establishes strict technical standards for 5G BWA equipment, mandating compliance with international norms, strictly limiting subscriber stations to indoor use, and requiring wired power sources to ensure the high stability demanded by manufacturing environments.

The Domestic Component Level (TKDN) policy acts as a primary market filter and investment incentive. Critically, the MoI’s Regulation No. 35/2025 now explicitly includes "Industry 4.0 Support Services" within the TKDN calculation scope. This strategic inclusion incentivizes international firms to localize their 5G solutions, engineering, and AI/IoT services, ensuring investment translates into high-value local economic development. The feasibility of this approach is demonstrated by the Pegatron smart factory in Batam, which successfully deployed a 5G Standalone (SA) private network in the 2.3GHz band in partnership with Telkomsel, connecting hundreds of machines and AGVs to enable flexible, high-efficiency production.

Indonesia's manufacturing sector is poised for a significant transformation, exhibiting high strategic intent despite low current maturity in smart manufacturing adoption, according to the survey. A substantial 38.1%of firms are currently in the "planning/experimentation" phase, signaling an early-stage market. However, the commitment is strong: nearly 60% of businesses view smart manufacturing as "critical" or "highly important," and over 61.9% project more than an increase in investment over the next five years, setting the stage for major future capital expenditure.

This transition is driven less by cost cutting and more by a strategic pivot towards value enhancement and global competitiveness. The top driver is "Improving Product Quality", surpassing cost reduction, followed closely by "Enhancing Production Efficiency". This ambition reflects a desire to move beyond basic production towards a sophisticated, value-added model that meets higher quality standards.

The technology adoption path is pragmatic and foundational, focusing on low-barrier tools like Cloud Computing, Big Data Analytics, and the Industrial Internet of Things (IIoT) for initial data visualization and decision support. Critically, the prioritization of Artificial Intelligence (AI) indicates an imminent shift from basic digitalization to demand for intelligent, predictive applications.

The pace of adoption is primarily constrained by two core, interconnected challenges: uncertainty of funding and Return on Investment (ROI) and a pervasive "Lack of adequate talent or technology". The absence of quantifiable, proven ROI, exacerbated by a lack of skilled personnel to effectively deploy and optimize new systems, is delaying the scaling of pilot projects.

To unlock Indonesia's modernization potential, a "gradual-high-return" strategy is essential. Technology providers should prioritize SaaS/subscription models to lower upfront capital risk, focusing on solutions that deliver rapid, measurable gains in areas like quality assurance and equipment uptime. Concurrently, government and APEC partners must concentrate on developing specialized IIoT and industrial AI talent pools and establishing "lighthouse factories" to publicly validate and showcase the tangible economic returns of smart manufacturing. By mitigating the anxieties of capital risk and talent scarcity, the sector can accelerate its modernization journey.

2.3 Japan

Since 2018, Japan's Ministry of Internal Affairs and Communications (MIC) has advanced the Local 5G initiative to empower industries and local communities with autonomous, high-performance networks. By granting local 5G licenses to enterprises since 2019, Japan has accelerated digital transformation across manufacturing, logistics, and healthcare sectors.

A key institutional innovation links spectrum rights to property ownership, ensuring that network control and data remain fully within the operator's domain. This framework addresses manufacturers' concerns over OT data security and enables seamless OT–IT integration for mission-critical systems such as robotics and production monitoring.

To lower barriers, firms like NEC and Fujitsu provide affordable solutions for SMEs, while spectrum usage fees remain minimal—only JPY 2,600 per base station annually. As a result, over 1,800 organizations have applied for Local 5G licenses since 2019, signaling strong private-sector uptake.

Japan's broader innovation framework aligns with this vision. On 6 June 2025, the Cabinet approved the Comprehensive Innovation Strategy 2025, highlighting AI, semiconductors, quantum technologies, digital infrastructure, renewable energy, and regenerative medicine as key domestic priorities. The strategy positions Beyond 5G/6G and AI as the twin pillars for industrial revitalization and societal resilience—particularly in addressing labor shortages and enhancing productivity.

It calls for an integrated pipeline from fundamental research to social implementation, emphasizing collaboration with local innovation hubs. Furthermore, Japan prioritizes data platforms and talent development to sustain technological competitiveness and secure its leadership in next-generation communications within the global digital economy.

Survey findings from Japan reveal a distinctive paradox in its smart manufacturing transition—strong technological ambition constrained by limited activation. Japanese manufacturers display high expectations for real-time and predictive capabilities enabled by 5G and AI, yet face systemic integration barriers, legacy infrastructure complexities, and funding limitations that hinder practical adoption.

The primary obstacle is not technological awareness but the difficulty of embedding new digital systems into deeply entrenched, customized legacy frameworks. This historical rigidity has slowed the diffusion of next-generation technologies, particularly across small and medium-sized enterprises (SMEs), which remain less capable of adopting advanced solutions compared to large manufacturers.

Despite these structural constraints, Japan's industrial strategies are notably coherent. Over the next five years, firms identify 5G connectivity, automation, and AI/machine learning as their top technological priorities—a synergistic trio spanning infrastructure, execution, and decision-making layers. Among them, 5G is recognized as the essential enabler for high-bandwidth, low-latency, and large-scale IoT environments fundamental to smart factories. Integrated deployment of these technologies is expected to address key operational challenges, enhancing flexibility, real-time monitoring, and predictive maintenance capacity.

While enthusiasm for high-value applications such as autonomous robotics, predictive maintenance, and anomaly detection is strong, the overall demand intensity is rated as moderate. This reflects a cautious view of market maturity and highlights the uneven diffusion of smart manufacturing—driven by major enterprises while SMEs lag behind. Respondents emphasize the need for greater R&D investment, knowledge sharing, technology transfer, and access to international best practices to lower experimentation costs and accelerate alignment with global standards.

Human capital remains another critical issue. Low female participation in Japan's manufacturing sector represents both a social and strategic vulnerability. In a global context emphasizing diversity and inclusion, respondents call for transparent recruitment frameworks and leadership-led cultural reform to strengthen innovation capacity and workforce sustainability.

Overall, Japan stands at a pre-inflection stage in its smart manufacturing evolution. Government initiatives and digital transformation subsidies are laying the groundwork, but realizing large-scale transformation will require systemic legacy modernization, SME empowerment, and workforce restructuring. Through coordinated advances in policy, technology, and talent, Japan can translate its strong potential into active transformation, reinforcing its competitiveness and resilience within the global supply chain.

2.4 Republic of Korea

According to the "2024 Smart Manufacturing Innovation Survey" released by Republic of Korea's Ministry of SMEs and Startups and the Smart Manufacturing Innovation Promotion Group on 28 April 2025, Korean SMEs have made notable strides in smart manufacturing. Among 163,273 factory-operating SMEs, 19.5% (over 30,000 enterprises) have implemented smart factories, while 75.5% are at early stages of digitalization. Overall smart factory utilization exceeds 80%, yet AI adoption remains limited (~0.1%), indicating that although digital infrastructure is broadly deployed, AI-driven capabilities are still nascent.

This development reflects alignment with the government's 2020 "AI- and Data-Driven Advanced Manufacturing Innovation Strategy for SMEs," which targets the establishment of 1,000 AI- and 5G-enabled smart factories by 2025. The strategy positions 5G networks as the backbone for digital transformation, enhancing operational efficiency, flexibility, and competitiveness across the manufacturing sector.

Since 2019, the commercial rollout of 5G has been complemented by the Ministry of Science and ICT (MSIT) and affiliated agencies through the "5G Smart Factory Advancement Strategy." This initiative promotes high-speed, low-latency private 5G networks for SMEs, supported by spectrum allocation, technical guidance, and financial incentives to tailor networks to specific production processes. Efficient policy execution is evidenced by the issuance of the "5G Private Network Policy Plan" and the "5G Dedicated Frequency Supply Plan" within ten months in 2021, stimulating both 5G B2B market competitiveness and enterprise-level digital transformation. Republic of Korea's coordinated policy-industry model offers a valuable reference for APEC economies seeking to integrate governance and technology in advancing smart manufacturing.

Survey insights indicate that structural cost pressures, rather than policy ambition alone, are the primary drivers of manufacturing transformation. High labor costs and skilled worker shortages have elevated smart manufacturing from an optimization tool to a strategic necessity for cost control and global competitiveness.

Technologically, Korean manufacturers demonstrate a pragmatic, data-driven approach. Widespread use of real-time analytics, traceability, and quality control systems indicates a mature digital foundation enabling process optimization. However, significant technical barriers persist, particularly in adopting 5G and AI. Fragmented standards, integration complexity, and cross-domain talent shortages hinder scalable deployment.

Market demand is exceptionally strong. Respondents consistently view 5G applications as critical to supply chain resilience, highlighting smart manufacturing as a strategic instrument for local economic security and global supply chain alignment. Nonetheless, deployment remains uneven: leading conglomerates advance aggressively, whereas SMEs face resource and technical constraints. Bridging this divide is a policy priority.

Respondents emphasize the need for technology transfer, knowledge sharing, and access to global best practices. The shift in focus from equipment acquisition to capability building underscores the importance of:

- Integration Knowledge: Aligning legacy IT/OT systems with 5G and AI technologies.
- Standardization Pathways: Adopting international standards suited to Republic of Korea's industrial ecosystem.

For APEC, these findings highlight opportunities for regional cooperation, including cross-economy knowledge platforms, technical workshops, and pilot standardization initiatives to accelerate high-value technology deployment.

Current female participation in manufacturing roles remains between 0–40%, with opportunities for improvement. Key strategies include family-friendly work environments and work-life balance promotion. As 5G-enabled smart manufacturing facilitates remote operations and AI-assisted workflows, flexible, less physically demanding roles could further enhance gender inclusion.

Republic of Korea's smart manufacturing landscape reflects high-intensity strategic demand amid implementation and knowledge-integration challenges. Future leadership depends on overcoming 5G/AI adoption barriers, bridging enterprise-scale disparities, and strengthening international collaboration and talent development. The Korean experience provides a model for APEC economies aiming to advance industrial competitiveness through integrated governance, technology adoption, and capability building

2.5 Peru

Peru is one of the most stable and steadily growing economies in Latin America, with a GDP of USD 280 billion in 2024 and a projected average annual growth rate of 2.6% through 2030. Low debt levels and sound macroeconomic fundamentals provide a solid foundation for industrial expansion. The government's "Digital Transformation Agenda 2030" focuses on industrial automation, cybersecurity, and smart logistics, signaling a clear policy direction.

Peru's manufacturing sector is highly diversified, spanning food processing, metalworking, textiles, and chemicals. It accounts for 12% of GDP and employs over 1.4 million people. More than 40% of large manufacturers have adopted Industry 4.0 technologies, while SMEs accelerate digitalization through initiatives such as Innovate Peru and Produce 4.0. Innovation networks, such as CITE, along with advanced tools like digital twins and predictive maintenance, are enhancing production efficiency and export readiness.

Looking ahead to 2025–2035, Peru's manufacturing sector is projected to grow at approximately 8% annually, driven by automation, sustainability, and export diversification strategies. Leveraging innovation capacity, skilled labor, and modern infrastructure, Peru is positioning itself as a competitive manufacturing hub in Latin America, offering collaboration and investment opportunities for APEC economies.

On digital infrastructure, Peru's Ministry of Transport and Communications (MTC) officially approved the implementing regulations for Legislative Decree No. 1627 in March 2025, marking the formal start of standardized 5G and next-generation public telecommunications deployment. From an industry perspective, this regulatory framework strengthens domestic connectivity, accelerates digital transformation, boosts overall productivity, and narrows technology adoption gaps.

Deputy Minister Carla Sosa Vela emphasized that the regulation is both forward-looking and highly applicable, aiming to stimulate local technology ecosystems and comprehensively enhance local telecommunications capacity. Its implementation is expected to directly support the upgrading of Peru's digital ecosystem and industrial structure. Furthermore, MTC highlighted that 5G deployment not only reinforces foundational connectivity but also serves as a key driver for innovative industrial applications, such as smart mining and the integration of autonomous sensing technologies, demonstrating the sector's potential for high-value manufacturing and innovation.

According to the survey response from Javier Escajadillo, CEO of TelVentures Consulting, Peru's smart manufacturing sector is at a critical inflection point: aging infrastructure coexists with strong potential for advanced technology adoption. Industry stakeholders express high expectations for 5G-enabled digital transformation; however, implementation faces significant internal constraints and external resource gaps.

Peru's manufacturing industry exhibits typical structural challenges: "aging equipment and legacy systems" and "difficulty integrating new technologies" are major transformation bottlenecks. This indicates that most companies must first invest substantial resources in infrastructure modernization before advancing digitalization. Furthermore, "limited investment capacity" and "barriers to adopting 5G and AI" mutually reinforce each other, highlighting clear constraints on capital-intensive technology upgrades. While basic automation and real-time data analytics have been adopted in some firms, overall application intensity remains "neutral," suggesting that technology penetration is emerging but has yet to achieve large-scale deployment.

Notably, surveyed companies demonstrate strategic interest in advanced 5G applications, particularly in supply chain resilience, which they rate as "high impact." From an application perspective, "real-time, remote, and intelligent operations" are key focus areas, including "advanced real-time monitoring" and "AI anomaly detection," directly addressing operational pain points such as lack of immediate monitoring and predictive maintenance. Attention to "digital twins" and "remote equipment control" indicates that Peruvian manufacturers aim to leverage virtualization to enhance operational flexibility and manage assets across regions.

This pattern clearly positions 5G as the core enabling technology for Peru's manufacturing sector to transition from an "inefficient and inflexible" model to one characterized by "resilient supply chains and intelligent decision-making." Prioritizing 5G as a critical technology over the next five years is therefore strategically justified. To convert 5G's potential into tangible value, Peru must address two critical gaps: budget and knowledge. Recommendations include increasing technology development budgets and strengthening external support, such as international investment, technology transfer, knowledge sharing, and adoption of global best practices and standards.

Overall, Peru's market demand for smart manufacturing is rated as "neutral," consistent with its current adoption intensity. While demand is nascent, overcoming capital and knowledge constraints could enable smart manufacturing to become a key driver of Peru's industrial growth in the coming years.

2.6 The Republic of the Philippines

The Philippines' economy in 2025 remains resilient, supported by robust domestic demand despite moderating growth. GDP expanded by 5.5% in the second quarter, primarily driven by strong household consumption and increased government spending, which grew by 8.7%. For the full year, growth is projected around 5.5%, with inflation successfully tamed and expected to remain low. The government aims to sustain infrastructure investment at 5%–6% of GDP, while monetary policy has shifted into an easing phase to support economic momentum.

Externally, global trade policy uncertainty and geopolitical tensions pose challenges, while domestically, frequent climate shocks remain a key risk. Nonetheless, structural reforms in infrastructure, foreign investment, and digitalization, alongside greater financial inclusion through mobile and internet access, are expected to strengthen long-term competitiveness.

The manufacturing sector showed mixed performance, slowing in early 2025 but rebounding by August, driven by food, beverage, and electrical equipment production. Capacity utilization reached 76.6% in mid-2025, reflecting steady demand. The government continues to position The Republic of the Philippines as a hub for smart and sustainable manufacturing, with the Board of Investments evaluating over PHP 33 billion in new projects. Growing female participation in high-precision and electronics manufacturing highlights the sector's evolving workforce and inclusiveness.

The APEC of The Republic of the Philippines's survey collected four responses from key representatives in government-affiliated science and research institutions, including the Department of Science and Technology (DOST) and public universities. The results provide a snapshot of an emerging smart manufacturing landscape that is gaining momentum but remains constrained by structural and workforce challenges.

Across respondents, the most frequently cited issues are shortages of skilled labor, high labor costs, and aging production equipment, reflecting a manufacturing base still in transition toward Industry 4.0. Despite these barriers, most respondents report that smart manufacturing technologies are active or moderately applied, particularly in automation, remote operations, and real-time data analytics.

Interest in 5G applications is consistently high, with all respondents highlighting real-time monitoring with analytics, AI-driven diagnostics, and predictive maintenance as the most promising use cases. Three of four respondents rated the expected impact on supply-chain resilience as high or very high, indicating strong optimism regarding the potential productivity and efficiency gains from 5G-enabled solutions.

The top challenges that 5G smart manufacturing could address include low production efficiency, limited operational flexibility, and lack of predictive maintenance capability. Looking ahead, the most needed technologies over the next five years are 5G connectivity, automation, artificial intelligence, machine learning, and digital twins.

Policy priorities emphasize talent training and education, supportive government policies, and increased technology development budgets to accelerate industrial upgrading. Demand for smart manufacturing is rated strong or very strong by all respondents, underscoring broad confidence in its strategic importance to domestic competitiveness.

Overall, the Philippines' manufacturing ecosystem demonstrates clear awareness of digital transformation priorities but requires stronger workforce development, policy coordination, and infrastructure investment to achieve large-scale, sustainable smart manufacturing deployment.

2.7 Singapore

Singapore's economy expanded by 2.9% in Q3 2025, surpassing expectations but moderating from 4.5% in Q2. Analysts project a softer pace in Q4 due to persistent global trade tensions, though the full-year GDP forecast has been upgraded to 1.5%–2.5%. The Monetary Authority of Singapore (MAS) maintained its monetary policy in October to ensure price stability, with core inflation expected to average 0.5% for the year.

Manufacturing, a cornerstone of Singapore's economy contributing over one-fifth of GDP, experienced a notable slowdown, particularly in biomedical and electronics output, with August output down 7.8% year-on-year. However, the sector remains central to long-term growth under the "Manufacturing 2030" plan, which aims to expand output by 50% through innovation, digital transformation, and advanced technologies such as robotics and 3D printing. Meanwhile, construction continues to show resilience due to strong contract activity, and services like accommodation and food are buoyed by rising international visitors.

Looking ahead, Singapore's economic momentum faces external headwinds from trade frictions and global demand uncertainty. Nonetheless, targeted investments in artificial intelligence, advanced manufacturing, and stable financial conditions are expected to partially offset these challenges, supporting Singapore's transformation toward a high-value, innovation-driven economy.

The APEC Singapore survey gathered a response from a senior director representing the IT services sector, providing a perspective centered on technology integration and workforce issues within Singapore's manufacturing ecosystem. The findings indicate that while Singapore remains technologically advanced, the manufacturing sector continues to face labor-related and cost-based constraints, which influence the pace and scope of digital transformation.

The key challenges identified include a shortage of skilled workers, high labor costs, and limited operational flexibility—all of which hinder the broader application of smart manufacturing technologies. Despite these challenges, smart manufacturing adoption is reported as active, with a focus on real-time data analytics as the primary technology currently in use.

Interest in 5G applications centers on advanced real-time monitoring, AI-driven analytics, and predictive maintenance, though the overall perceived impact on supply-chain resilience is assessed as low at the current stage of deployment. The respondent noted that automation, AI and machine learning, and cybersecurity solutions are among the most critical technologies needed for the next five years, aligning with Singapore's broader Industry 4.0 initiatives.

Demand for smart manufacturing solutions is rated as strong, driven by the need to improve operational efficiency and workforce productivity. To accelerate adoption, the respondent emphasized the importance of international collaboration—including partnerships for technology co-development, skills exchange, and joint innovation programs—to leverage global expertise and market opportunities.

In summary, Singapore's smart manufacturing ecosystem demonstrates strong technological readiness but faces structural labor and cost challenges. Continued cross-border collaboration and workforce development are viewed as key enablers for sustaining growth and maintaining competitiveness within the evolving Asia-Pacific industrial landscape.

2.8 Chinese Taipei

Chinese Taipei's economy in 2025 is positioned for steady yet uneven growth. Benefiting from the global surge in artificial intelligence (AI) and semiconductor demand, exports and investment have become the primary engines of expansion. The Chung-Hua Institution for Economic Research (CIER) has revised Chinese Taipei's GDP growth forecast upward to 5.45%, citing robust performance in the high-tech sector and strong capital expenditure linked to AI infrastructure and semiconductor manufacturing.

Nevertheless, domestic consumption remains moderate due to inflationary pressures and a softening real estate market. Broader economic performance reflects a structural imbalance—dynamic growth in emerging technology industries contrasted by sluggish activity in traditional sectors. Meanwhile, persistent challenges such as labor shortages, demographic aging, carbon reduction mandates, and global trade uncertainties continue to test industrial resilience.

In response, the government is advancing a comprehensive manufacturing strategy centered on investment expansion, innovation-driven R&D, talent cultivation, and industrial clustering. The goal is to strengthen Chinese Taipei's leadership in high-value manufacturing while supporting traditional industries in their transformation and upgrading. Through this dual-track policy approach, Chinese Taipei aims to enhance productivity, secure supply chain stability, and build a more sustainable and competitive industrial base capable of withstanding global economic volatility.

The APEC Chinese Taipei survey collected seven responses from diverse organizations, including telecom operators, cybersecurity firms, system integrators, research institutes, and consulting entities. The findings reveal a consistent trend: Chinese Taipei's manufacturing ecosystem is actively transitioning toward AI- and 5G-enabled smart production, though adoption remains uneven across industry types.

High-technology sectors—particularly semiconductors and electronics—are driving strong demand for private 5G networks, automation, and AI-based predictive maintenance. Six of seven respondents expressed strong or very strong demand for smart manufacturing, with five reporting that 5G applications will have a high or very high impact on supply-chain resilience. Priority use cases include real-time monitoring with analytics, AI-assisted diagnostics, edge inference, and remote equipment control.

Across all respondent types, major challenges include legacy system integration, skills shortages, and cybersecurity concerns. Telecom and system integrator respondents emphasized the need for investment incentives and workforce development, while research institutes and consultants highlighted the importance of policy support and knowledge transfer to accelerate industrial transformation.

Over the next five years, technology priorities converge on 5G connectivity, automation, AI/ML, cybersecurity, and digital twins. Policy expectations focus on technology R&D funding, international collaboration, and talent cultivation. Respondents also call for enhanced mechanisms for technology transfer, global best-practice sharing, and international investment support to strengthen Chinese Taipei's participation in regional innovation networks.

Gender inclusion data show that women currently comprise 0–60% of the workforce in surveyed organizations, with most between 0–20%. All respondents endorsed transparent HR mechanisms, leadership commitment, and family-friendly policies to promote women’s participation in smart manufacturing.

Overall, the survey indicates that Chinese Taipei possesses strong technological foundations but must balance innovation momentum with inclusive workforce policies and coordinated industrial upgrading.

2.9 Thailand

Thailand has firmly integrated Smart Manufacturing into its domestic 'Thailand 4.0' and 'Digital Thailand' strategies, positioning robotics, automation, and smart electronics as core 'New S-Curve' industries to drive a transition towards a value-and-innovation-driven economy.

To accelerate the deployment of IIoT applications (e.g., digital twins, machine vision), the National Broadcasting and Telecommunications Commission (NBTC) introduced a globally recognized, innovative policy. The NBTC allocates 100 MHz of 4.8 GHz spectrum free-of-charge to factories and industrial estate operators for exclusive, internal, non-commercial use.

This "free-and-direct" Private Network Operator (PNO) model significantly lowers the total cost of ownership for enterprises and provides a unique competitive advantage for high-reliability, low-latency manufacturing environments in the ASEAN region.

Investment and Geographical Focus

- Financial Incentives: The Board of Investment (BOI) offers strong incentives, including Corporate Income Tax (CIT) exemptions of up to 8-10 years for high-value-added projects (e.g., smart electronics, advanced PCBs). Furthermore, the BOI provides tax exemptions to reward existing factories for digitalization upgrades under its I4.0 Transformation Rewards.
- Eastern Economic Corridor (EEC): The EEC is the core geographical driver, where advanced infrastructure has successfully attracted multinational corporations like Midea and Mitsubishi Electric to implement 5G smart factory pilots.

As the convergence of Information Technology (IT) and Operational Technology (OT) accelerates, manufacturers must navigate stricter compliance:

- Cybersecurity: The Cybersecurity Act (CSA) is expanding its scope to include 'Industrial Work,' mandating Critical Information Infrastructure (CII) operators to conduct annual risk assessments.

- Data Privacy: The fully enforced Personal Data Protection Act (PDPA) requires smart factories deploying 5G IIoT applications—especially those involving employee biometrics or health monitoring—to ensure strict compliance for data collection and processing.

Finally, government agencies like the Digital Economy Promotion Agency (DEPA) provide crucial funding and technical guidance to help Small and Medium-sized Enterprises (SMEs) bridge the digital divide.

Survey findings reveal that Thailand faces enduring structural barriers—legacy systems and a shortage of skilled labor—prompting investment to focus on system integration and automation. The economy's smart manufacturing progress is therefore assessed as "Neutral," reflecting a phased, pragmatic approach.

5G connectivity is identified as Thailand's top technological priority for the next five years, aimed at resolving inefficiencies in production, monitoring, and automation. Strategic applications such as real-time monitoring and supply chain tracking signal a shift toward data-driven agility and AI-powered predictive manufacturing, enhancing regional competitiveness and supply chain resilience.

Government support—through grants, tax incentives, and PPPs—emphasizes inclusive transformation and SME participation. Thailand's readiness for technology transfer and knowledge exchange further demonstrates openness to APEC collaboration.

Though female participation remains low, recognition of women's leadership and analytical skills aligns with the evolving needs of data-centric manufacturing.

In essence, Thailand's 5G strategy represents a measured yet decisive modernization path, combining technology adoption with human capital development to achieve sustainable industrial resilience.

3. Trends in 5G Technology Integration

3.1 Technical Core: 5G System Integration and the Network Paradigm Shift

To understand the trajectory of industrial connectivity, it is essential to analyze why 5G is replacing or complementing existing connection technologies in industrial scenarios. While factories have long relied on wired Ethernet and wireless Wi-Fi, these legacy technologies face physical and technical limitations when confronted with the demands of future factories, which emphasize "flexible production" and "mobile robotics."

In addition, 5G represents not merely a replacement of connectivity technologies, but a system-level architectural shift. By integrating Software-Defined Networking (SDN) and Network Function Virtualization (NFV), 5G enables connectivity to become a programmable resource that can be dynamically aligned with production objectives, transforming networks from static infrastructure into adaptive operational assets.

This architectural flexibility is particularly valuable for brownfield factories, where gradual and wireless integration of new equipment reduces retrofit costs and production downtime. An important consideration for SMEs across APEC economies.

3.1.1 Analysis of Limitations in Legacy Industrial Networks (Wi-Fi & Ethernet)

3.1.1.1 The Physical Constraints of Ethernet

Industrial Ethernet has long dominated the Operational Technology (OT) network layer due to its stability and interference resistance. However, its biggest drawback lies in the "cabling."

- **Lack of Reconfigurability:** In the context of supply chain resilience, production lines must be reconfigurable within hours to adapt to disruptions (e.g., switching products due to material shortages). Wired networks require days or weeks for re-cabling, incurring high labor and downtime costs.
- **Mobility Restrictions:** Physical cables severely limit the deployment range and flexibility of mobile assets, such as Automated Guided Vehicles (AGVs).

3.1.1.2 Wi-Fi's Spectrum Competition and Mobility Defects

While Wi-Fi (even Wi-Fi 6/6E or 7) offers wireless convenience, it faces inherent challenges in industrial environments:

- **Interference in Unlicensed Spectrum:** Wi-Fi operates on unlicensed spectrums, competing with Bluetooth, microwaves, and signals from neighboring facilities. In metal-heavy industrial environments, this leads to packet loss and jitter. While acceptable for IT applications, this latency is critical for millisecond-precise control of robotic arms, posing safety risks.
- **Handover Discontinuities:** Wi-Fi handover mechanisms often cause brief disconnections when AGVs move across different Access Points (APs). These "dead zones" trigger emergency stops, impacting logistics efficiency. 5G, leveraging cellular architecture, supports seamless handovers for objects moving up to 500 km/h, ensuring continuous connectivity.
- **Security Vulnerabilities:** Traditional Wi-Fi relies on password exchange (WPA), which is susceptible to attacks. 5G utilizes hardware-level authentication (SIM/eSIM) and Network Slicing to logically isolate critical OT data from general traffic, offering telecommunication-grade security.

These limitations highlight why Wi-Fi remains suitable primarily for non-critical IT applications, while mission-critical industrial operations increasingly require deterministic and carrier-grade wireless solutions.

3.2 Industrial Translation of 5G Characteristics: URLLC, mMTC, and eMBB

5G architecture allows for customized Quality of Service (QoS) tailored to specific industrial scenarios through three primary technical pillars:

- **Ultra-Reliable Low-Latency Communication (URLLC):**
  - *Role:* The cornerstone of industrial control.
  - *Capability:* Promises latency as low as 1 ms and 99.9999% reliability.
  - *Application:* Enables "Wireless Closed-Loop Control." For instance, in semiconductor wafer dicing, sensors detect minute vibration shifts and adjust tools within milliseconds—a feat achievable wirelessly only via URLLC.
- **Massive Machine-Type Communication (mMTC):**
  - *Role:* Key to full-domain visualization.
  - *Capability:* Supports up to one million connections per square kilometer. Incorporates RedCap (Reduced Capability) technology to lower chip complexity and cost for sensors.
  - *Application:* Critical for supply chain resilience. It allows granular tracking of individual pallets, material barrels, or component boxes,

enabling end-to-end transparency and immediate bottleneck identification.

- **Enhanced Mobile Broadband (eMBB):**
    - *Role:* Enabler of advanced vision and collaboration.
    - *Capability:* Provides transmission speeds up to 10 Gbps.
    - *Application:* Transmits high-resolution data for AI Optical Inspection (AOI) (4K/8K images) and supports Augmented Reality (AR) for remote expert guidance.

Importantly, these three pillars operate in convergence rather than isolation. Modern manufacturing processes often require low-latency control, massive sensing, and high-bandwidth visual data simultaneously, a combination uniquely supported by 5G's unified architecture.

3.3 Deep Integration of Private 5G with IT/OT

Manufacturing sectors across APEC economies are accelerating the transition from public 5G to **Private 5G (NPN)**. Private networks offer three decisive advantages:

1. **Data Sovereignty:** Sensitive production data remains on-premises.
2. **Resource Exclusivity:** Bandwidth is dedicated solely to production lines.
3. **Customized Optimization:** Parameters can be tuned, such as increasing uplink ratios for AOI image uploads.

Beyond technical benefits, Private 5G plays a strategic role in bridging long-standing IT/OT silos. Through logical network slicing, diverse performance requirements can coexist on a single physical network, enabling both operational determinism and enterprise-level scalability.

This capability supports multinational manufacturers by enabling standardized global architectures while retaining local flexibility to comply with regulatory and spectrum conditions.

Table: Analysis of Wireless Technology Suitability in Smart Manufacturing

Application Scenario	**Technical Requirement**	**Wi-Fi 6/7**	**Public 5G**	**Private 5G**
Office IT Network	High bandwidth, low cost	★★★	★★	★
Mobile Robots (AGV/AMR)	Seamless handover, low latency	★	★★	★★★
AI Optical Inspection (AOI)	High uplink bandwidth	★★	★★	★★★ (Configurable Uplink)
Human-Machine Safety	High reliability (URLLC)	☆	★	★★★
Massive Asset Tracking	High density (mMTC)	★★	★★★	★★★
Remote AR Maintenance	High bandwidth, mobility	★★	★★★	★★★

(Note: ★★★ Excellent, ★★ Good, ★ Average, ☆ Not Recommended)

Summary: 5G forms a "layered complementarity" with Wi-Fi. Wi-Fi serves IT networks, while Private 5G assumes control of critical OT networks.

3.4 Practicing Resilient Supply Chains: From Prediction to Reconfiguration

Supply chain resilience relies on "foreseeing the invisible" and "adapting to the uncontrollable."

5G transforms resilience from a reactive capability into a dynamic, data-driven process by enabling continuous sensing, real-time analytics, and rapid reconfiguration across production and logistics systems.

3.4.1 Enabling Reconfigurable Manufacturing Systems (RMS)

Traditional rigid production lines struggle with market volatility. 5G enables **Reconfigurable Manufacturing Systems (RMS)**, where wireless connectivity allows factory managers to move workstations, robots, and conveyors with the flexibility of building blocks.

- *Case Analysis:* In automotive manufacturing, if a shortage halts Model A production, 5G allows rapid layout and program switching to assemble Model B, minimizing capacity idleness.

3.4.2 5G + TSN: Breakthrough in Wireless Time-Sensitive Networking

Realizing RMS requires **Time-Sensitive Networking (TSN)** for deterministic data delivery.

- *Technological Breakthrough:* 3GPP R16/R17 standards support 5G-TSN integration. This allows the 5G network to act as a precise clock, synchronizing wireless robots with microsecond-level accuracy. This solves historical challenges in wireless multi-axis coordination, making "wireless" and "modular" production lines a reality.

3.4.3 Predictive Maintenance (PdM)

5G enables the streaming of raw, uncompressed high-frequency vibration and acoustic data to Edge AI models.

- *Benefit:* Studies indicate 5G-based PdM can reduce maintenance costs by 25-30% and virtually eliminate unplanned downtime, allowing APEC manufacturers to make reliable delivery commitments.

3.4.4 End-to-End Real-Time Visualization

- **5G RedCap Application:** Lower costs allow trackers on individual parcels, transmitting location and condition data.
- **Port Automation:** Major APEC ports (Singapore, Busan, Shanghai) utilize 5G for remote-controlled RTG cranes and automated trucks, enabling 24/7 operations and mitigating port congestion.

3.5 Human-Centric Innovation: 5G Human Sensing and Collaboration

Aligning with the PPSTI_103_2024A proposal, the focus shifts to "Human Sensing" and "Contactless HCI".

Beyond safety enhancement, 5G-enabled human-centric applications reduce cognitive load and augment worker capabilities, enabling personnel to focus on higher-value decision-making rather than manual operation.

Remote operation and AR-assisted workflows also decouple expertise from physical location, supporting inclusive workforce participation and gender equality.

3.5.1 5G Integrated Sensing and Communication (ISAC)

ISAC utilizes 5G radio waves (millimeter-wave) to scan environments like radar, detecting object position and subtle movements (breathing, gestures) without wearable devices.

3.5.2 Application: Contactless Human-Computer Interaction (HCI)

- *Gesture Control:* Personnel can operate cranes or flip electronic pages via gestures detected by 5G radar, reducing contagion risks and operational friction in cleanrooms or hazardous environments.

3.5.3 Application: Virtual Safety Fencing

- *Active Protection:* 5G ISAC creates invisible "electronic fences" around heavy machinery, triggering emergency stops via URLLC when intrusion is detected.
- *Health Monitoring:* The system can non-invasively detect fall incidents or respiratory distress via micro-Doppler effects.

3.5.4 Gender Inclusivity and Workforce Transformation

5G-enabled Remote Operation and AR support reduce reliance on physical strength, opening technical roles to a broader demographic and promoting gender equality in the workforce.

3.6 Sustainable Manufacturing: Energy Efficiency and Green 5G

Energy resilience is intrinsic to supply chain resilience. In addition to direct energy savings, 5G contributes to sustainability through improved resource efficiency, waste reduction, and transparent ESG data collection, supporting Scope 3 emissions management.

3.6.1 5G-Driven Granular Energy Management

- *Energy Visualization:* mMTC allows high-density deployment of energy sensors.
- *Dynamic Sleep Mode:* 5G's low latency allows devices to enter deep sleep immediately after tasks and wake instantly, generating significant cumulative energy savings.

3.6.2 Evidence of Efficiency

Data from Ericsson's 5G smart factory in Texas demonstrates a **24% reduction in energy consumption** and a **75% reduction in indoor water usage**. The energy savings from 5G-enabled vertical applications outweigh the network infrastructure costs.

3.6.3 Green Supply Chain and Scope 3 Emissions

5G assists in tracking Scope 3 emissions by optimizing logistics routes via connected fleets, reducing empty hauls and fuel consumption.

3.7 Regional Practices: Adoption Paths in APEC Economies

The diversity of adoption paths across APEC economies demonstrates that successful 5G integration depends not only on technology readiness, but also on policy alignment, ecosystem collaboration, and cross-border knowledge sharing.

3.7.1 Chinese Taipei: Precision Manufacturing Testbed

As the proposing economy, Chinese Taipei leverages its semiconductor and ICT strengths.

- *Case Study:* Pegatron and ASE have deployed Private 5G. Pegatron replaced Wi-Fi with 5G to resolve AGV disconnection issues, while 5G-supported AOI systems improved chip inspection yield.

3.7.2 Republic of Korea: Strategy-Driven Transformation

As the host economy for APEC 2025, Republic of Korea is driving its "5G+ Strategy."

- *Case Study:* The shipbuilding industry utilizes 5G for remote inspection and digital twin assembly. Hyundai utilizes 5G to coordinate robot swarms for customized vehicle production.

3.7.3 Southeast Asia: Leapfrog Development

- **Thailand:** Midea's factory in Chonburi established Southeast Asia's first fully 5G-connected factory.
- **Viet Nam:** Viettel and Pegatron collaborated on a 5G smart factory in Hai Phong for AR assembly.
- **Malaysia:** Petronas utilizes Private 5G for offshore platform monitoring. Malaysia aims to showcase 40 5G private network use cases.
- **Indonesia:** Telkomsel and Huawei partnered to implement 5G smart mining for remote heavy machinery operation.

3.7.4 Peru and United States: Diverse Application Spectrum

- **United States:** Ericsson's Texas factory illustrates how automation and energy efficiency can restore competitiveness.
- **Peru:** As the 2024 host, Peru emphasizes 5G applications in mining and agriculture to foster inclusive growth.

4. Case Studies and Experiences

4.1 5G-Enabled Smart Manufacturing: Driving Industrial Transformation

Many manufacturers face "data silos" caused by aging, isolated production equipment, which hinder real-time data collection and analysis. Existing wired Ethernet systems, though stable, are costly and inflexible, while Wi-Fi suffers from interference, latency, and security issues—often unreliable in dense factory settings. Re-cabling or adjusting Wi-Fi during line reconfiguration is time-consuming and expensive, slowing agile manufacturing. Moreover, legacy networks cannot meet the high-bandwidth, low-latency demands of AI-based inspection or real-time control, driving the need for next-generation connectivity.

Private 5G networks address these pain points by offering high throughput, ultra-low latency, and wired-level reliability without physical cabling. Compared to Wi-Fi, 5G provides greater bandwidth, higher device density, and stronger encryption, minimizing interference and ensuring secure data transmission. By deploying 5G, manufacturers can integrate fragmented systems, enabling seamless connectivity for AI analytics and intelligent automation. Case studies show 5G adoption can boost production and inspection efficiency by 15–20%, significantly strengthening supply chain resilience.

In essence, the contrast between traditional network limitations and 5G's flexibility, performance, and security is accelerating 5G adoption across industrial environments.

Private 5G Architecture and Characteristics

A private 5G network, or non-public network (NPN), is a dedicated system deployed within an enterprise facility. It typically includes exclusive radio units (RUs), distributed/central units (DUs/CUs), and an on-site core network hosted in a local data center or edge server. This architecture ensures full control over resources and data sovereignty, isolated from public 5G networks.

At the seminar, Mavenir presented flexible private network models—from operator-provided network slices to fully standalone Open RAN deployments—while PEGATRON emphasized open architectures using O-RAN technologies to enable end-to-end interoperability and multi-vendor innovation. Private 5G thus provides the flexibility and reliability needed for mission-critical industrial environments.

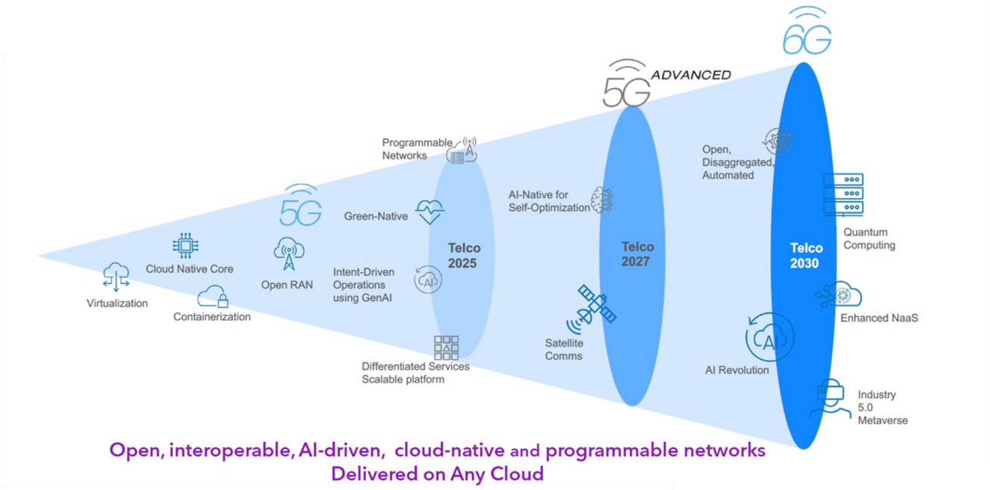

Figure 1. Mavenir - Building the future of networks today

Technically, private 5G aligns closely with smart manufacturing needs. Its ultra-low latency and high reliability support real-time wireless control for automation systems. Massive IoT capabilities allow thousands of sensors and robots to connect simultaneously, ensuring seamless data collection and factory digitalization. Enhanced security further distinguishes private 5G: dedicated spectrum and local data retention reduce interference and leakage risks. Chunghwa Telecom highlighted that customized encryption and access control keep sensitive production data off public networks.

Key enablers—network slicing and Multi-access Edge Computing (MEC)—extend private 5G's capabilities. Network slicing creates virtual sub-networks optimized for distinct tasks (e.g., isolating robot control traffic from office IT), while MEC enables local data processing and AI inference at the edge for minimal latency. For instance, PEGATRON's 5G factory deploys the User Plane Function (UPF) at the edge to process camera data in real time, enhancing responsiveness and offloading the core. Together, slicing and edge computing make private 5G a secure, high-performance foundation for Industry 4.0.

Practical Application Scenarios and Benefits

Private 5G networks in smart manufacturing have moved from concept to reality, as evidenced by the deployments shared by PEGATRON, Chunghwa Telecom, and the Korean case. Below are several typical application scenarios and their benefits:

AI Visual Inspection: Leveraging 5G to link high-speed cameras with edge AI enables real-time defect detection and process optimization. PEGATRON's 5G-enabled factory transmits live production images to AI models for instant quality checks, significantly lowering defect rates. Managers also use captured data to train staff and refine workflows, resulting in higher inspection accuracy, improved product quality, and reduced manual labor costs.

Autonomous Mobile Robots (AMRs/AGVs): Private 5G networks provide reliable, low-latency connectivity for fleets of AMRs and AGVs, overcoming Wi-Fi's roaming limitations. At PEGATRON's Indonesian plant, 5G dongles connect hundreds of machines and robots across 21 base stations, achieving fully automated material transport. The seamless 5G coverage enhances safety, efficiency, and logistics performance while reducing reliance on human-driven vehicles.

Digital Twin: 5G's high bandwidth and low latency enable real-time synchronization between physical factories and their digital twins. Using e-UM 5G networks, manufacturers like those in Republic of Korea can predict equipment failures and optimize processes through virtual simulations. With MEC-enabled 5G, digital twins support predictive maintenance and scenario testing, improving Overall Equipment Effectiveness (OEE) and minimizing downtime.

Remote Maintenance and Operations: 5G combined with AR/VR allows technicians to share live visuals with remote experts for real-time guidance, cutting troubleshooting time by up to 30%. In Republic of Korea, 5G private networks support AR-assisted maintenance and remote machinery control, boosting efficiency and safety. These applications eliminate travel needs and protect workers from hazardous environments.

Figure 2. 6G Forum - Private 5G AX use case in Republic of Korea

These scenarios demonstrate tangible benefits delivered by 5G. For instance, in production line reconfiguration: traditionally, retooling a line and updating network connections could require weeks of downtime, but thanks to wireless 5G, PEGATRON noted it cut the reconfiguration time for a large line by up to two weeks in its Indonesia factory. In terms of overall equipment effectiveness (OEE), 5G's support for real-time monitoring and predictive maintenance has markedly improved machine availability and product quality.

Furthermore, higher automation directly translates to lower labor costs and reduced operational risks. In summary, private 5G's applications on the factory floor are steadily proving their return on investment by boosting productivity, quality, and agility across the board.

Economic and Operational Impact

a. Higher Productivity and Equipment Effectiveness

One of the most immediate economic benefits of 5G-enabled manufacturing is a marked increase in production efficiency. With 5G's fast and reliable connectivity, factories achieve greater automation and more real-time decision-making. In the earlier examples, 5G cut production line reconfiguration times by weeks, translating to reduced downtime and opportunity cost.

Faster product changeovers and line adjustments allow companies to respond more flexibly to market demands, boosting order fulfillment rates. In parallel, Overall Equipment Effectiveness (OEE) improves significantly with 5G. Reports indicate that after 5G adoption, line downtime can be reduced and resource utilization increased, yielding a 15–20% gain in output efficiency.

The seminar also discussed how 5G-enabled predictive maintenance lowers equipment failure rates and repair durations, further improving machine availability. Collectively, these performance gains convert directly into lower unit production costs and higher profit margins.

b. Labor and Operational Cost Benefits

5G-enabled manufacturing also optimizes workforce allocation and reduces operating expenses. Automation improvements mean fewer labor hours are needed per unit of output, allowing companies to reassign workers from repetitive or hazardous tasks to higher-value roles. Meanwhile, applications like AR remote support enable expert resources to be shared across sites, obviating the need for each factory to staff a full in-house maintenance team, thereby saving personnel costs. Korea's Wizcore has found that SMEs, by subscribing to 5G private network services and remote support, can reduce the burden of maintaining their own IT/OT systems.

Additionally, predictive maintenance cuts unplanned downtime, avoiding the steep losses associated with equipment failures. Furthermore, improved yield and lower defect rates mean reduced material waste and rework costs – for example, PEGATRON's deployment of AI inspection significantly decreased the production of defective units, improving raw material utilization and yield. 5G also enables more precise energy management (e.g. smart sensing to adjust equipment power use in real time), which helps control manufacturing costs amid rising energy prices. In sum, 5G not only drives revenue growth but also enhances profitability through multifaceted cost savings.

c. Supply Chain Resilience and Agility

5G-powered smart manufacturing also has profound effects on supply chain management. On one hand, real-time data flows and cloud connectivity make supply chains more transparent, enabling early warnings of inventory shortfalls or transport disruptions. This visibility helps lower inventory holding costs and prevent stock-out production stoppages. The seminar noted that a 5G-connected smart factory can collaborate with suppliers in real time – for instance, production data can automatically feed back to suppliers to adjust raw material deliveries.

On the other hand, 5G's flexibility allows factories to switch production or redistribute capacity faster. In scenarios like a pandemic or sudden demand spikes, geographically dispersed plants can synchronize production instructions and quality standards over 5G, ramping up output in unison without missing delivery deadlines. This agility improves fulfillment reliability. The APEC findings highlighted that 5G adoption could boost supply chain efficiency by about 15–20%, enhancing regional economies' resilience to shocks. Therefore, 5G smart manufacturing not only positively impacts individual company performance, but also fortifies the robustness and agility of the broader supply chain.

Figure 3. PEGATRON - Translating Technology into Economic Value

The role of the government

Republic of Korea rebranded its private 5G initiative as e-UM 5G (meaning "connection"), focusing on non-public networks for specific areas like factories and campuses.

The government accelerated adoption by:

1. Opening up spectrum: Allocating the 4.7 GHz and 28 GHz bands for enterprises to apply and build their own networks, enabling non-telecom operators (like NAVER, POSCO Group, and Wizcore) to become licensed providers.
2. Promotion and Alliances: Convening the 5G+ Alliance of industry, academia, and research to create an e-UM 5G roadmap and accelerate adoption.
3. Financial Investment: Funding large-scale pilot projects in 2022 and 2023 involving multiple public and private entities.

This comprehensive approach—allocating spectrum, forming alliances, and investing in pilots—has rapidly established the e-UM 5G ecosystem, positioning private 5G as a cornerstone of Republic of Korea's smart manufacturing transformation.

Chinese Taipei is actively promoting private 5G development through spectrum allocation, financial incentives, and regulatory support, focusing on industrial applications.

Key initiatives include:

1. Spectrum & Fees: Designating the 4.8–4.9 GHz band for enterprise private 5G and significantly reducing frequency usage fees to encourage adoption.
2. Subsidies & R&D: The Ministry of Economic Affairs' Department of Industrial Technology (DoIT) provides special projects and subsidies for 5G smart

manufacturing R&D (e.g., funding ITRI and PEGATRON for O-RAN solutions and supporting overseas factory deployments).

3. Pilot Projects: Subsidies help deploy private 5G at local manufacturers (e.g., Ever Green Timber Products) to enhance efficiency.
4. Licensing: The Ministry of Digital Affairs (MODA) issues dedicated licenses, with 83 private 5G licenses and 24 license-exempt pilot cases granted by 2025, lowering entry barriers for SMEs with incentives like waived spectrum fees.
5. Local Supply Chain: A policy mandates that 40% of new 5G base station equipment must be sourced from domestic vendors to spur the local 5G supply chain.

Chinese Taipei's comprehensive approach—combining spectrum, financial aid, and public-private pilots—is designed to accelerate the rollout of 5G smart manufacturing.

4.2 Leveraging Smart Manufacturing to Create Sustainable and Resilient Supply Chains

In the face of multiple challenges such as labor shortages, rising energy costs, growing sustainability demands, and the need for greater resilience in global manufacturing, companies are rethinking how to build supply chains that can endure and thrive. Smart manufacturing – leveraging technologies like 5G, artificial intelligence (AI), and IoT – refers to factory systems that self-organize and minimize human intervention, powered by intelligent technologies.

The essence of smart manufacturing is intelligent coordination across the production ecosystem: machines and equipment communicate and work together to boost efficiency and reliability. However, realizing this vision depends on advanced digital infrastructure – particularly smart networks such as 5G that act as the digital nervous system connecting people, machines, and data in real time. Through these innovations, companies aim to create supply chains that are more resilient, adaptive, and sustainable.

This session examines how smart manufacturing can bolster supply chain sustainability and resilience from three key perspectives: Cybersecurity, AI Applications, and Supply Chain Resilience. It integrates insights and real-world examples shared by industry experts during the APEC 2025 post-conference seminar – including Trend Micro's recommendations on security strategies, Ataya's architectures and solutions for AI-driven smart manufacturing networks, and Itochu Techno-Solutions (CTC)'s analysis of supply chain resilience in Japanese manufacturing. The following sections provide an in-depth, structured analysis of each of these three areas.

Cybersecurity in Smart Manufacturing

As smart manufacturing integrates 5G, AI, cloud platforms, and OT, supply chains face new cybersecurity risks. Unlike 4G's closed systems, 5G's open architecture expands the attack surface by involving more vendors and components.

Trend Micro notes that shifting from proprietary 4G to open 5G ecosystems creates major supply chain security challenges. Smart factories now merge IT, OT, and CT networks with countless connected devices—each a potential attack vector. A single compromised node can enable lateral movement, leading to data breaches or operational disruption. Industry data shows that 75% of organizations have experienced ransomware, while 70% were breached via poorly managed interfaces. These threats, including software supply chain attacks, are key factors slowing 5G adoption in manufacturing.

AI compounds this risk: though 64% of companies plan to embed AI in 5G networks, an equal share worry about AI system vulnerabilities. As Trend Micro stresses, "without strong cybersecurity, resilience is impossible" in digital supply chains.

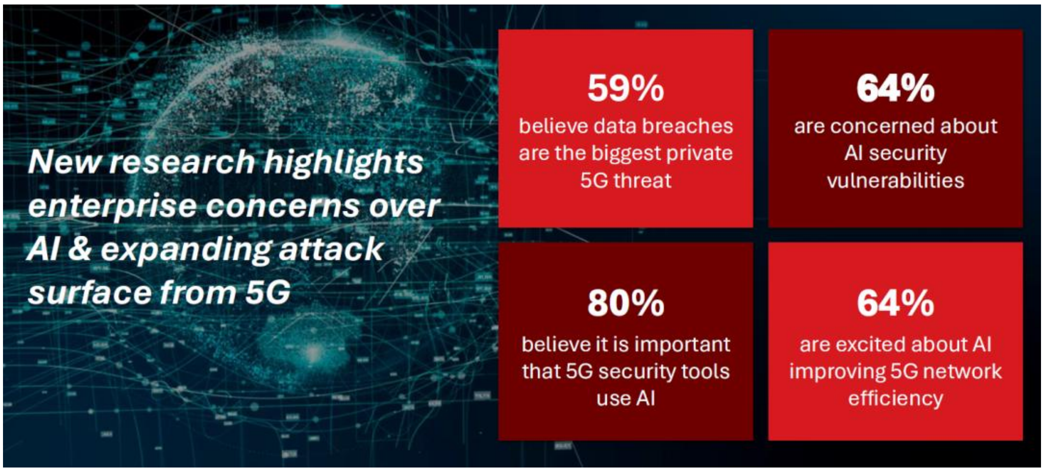

Figure 4. Trend Micro - Enterprise Mobile Meets AI

To mitigate risks, manufacturers must strengthen visibility and adopt a Zero Trust framework. This begins with mapping all IT/OT assets—including cloud and edge—to uncover vulnerabilities and eliminate blind spots. Companies should assess defenses from an attacker's viewpoint and apply Zero Trust principles: no implicit trust, continuous authentication, and micro segmentation to contain breaches. For instance, Ataya's private 5G solution uses Zero Trust to authenticate every device under a unified policy, preventing lateral movement.

Beyond prevention, firms need real-time detection and response capabilities to maintain operations during incidents. Trend Micro recommends an integrated Cyber Risk Exposure Management (CREM) platform that provides unified risk visibility, AI-driven threat assessment, and prioritized alerts. By aligning cybersecurity data with business risk metrics, such platforms help executives understand how cyber resilience underpins supply chain continuity.

In essence, digital supply chains demand end-to-end cybersecurity—anchored in visibility, Zero Trust, and continuous risk management—to sustain resilience and trust in 5G-enabled manufacturing.

AI Applications in Smart Manufacturing

Artificial intelligence (AI) has become a core enabler of smart manufacturing, driving efficiency and intelligence across the supply chain. Manufacturers are increasingly adopting AI to enhance product quality, reduce downtime, and optimize production. Predictive maintenance anticipates equipment failures through sensor data analysis; computer vision automates defect detection; and AI-driven demand forecasting enables agile production scheduling.

Over 60% of manufacturers plan to integrate AI into their 5G networks, expecting smarter and more adaptive operations. By leveraging real-time data and machine learning, AI supports decisions across all supply chain stages—from inventory management and production to distribution—enhancing flexibility and resilience against disruptions.

Maximizing AI's value requires balancing workloads between cloud and edge environments. The cloud excels at computation-heavy tasks like model training and digital twin simulations, while edge AI handles low-latency applications such as real-time quality inspection or autonomous robot navigation. Cloud-edge collaboration, enabled by 5G's high bandwidth and low latency, ensures seamless data flow and responsive decision-making—combining the cloud's analytical depth with the edge's immediacy.

Innovative architectures now merge AI with networking to strengthen manufacturing ecosystems. For example, Ataya's "Harmony" platform integrates 5G and edge computing under a unified connectivity fabric, offering Zero Trust security, micro segmentation, and flexible application deployment. It allows factories to host AI modules locally for real-time analytics while managing them via the cloud, even supporting an app-store-like environment for rapid onboarding of third-party OT applications.

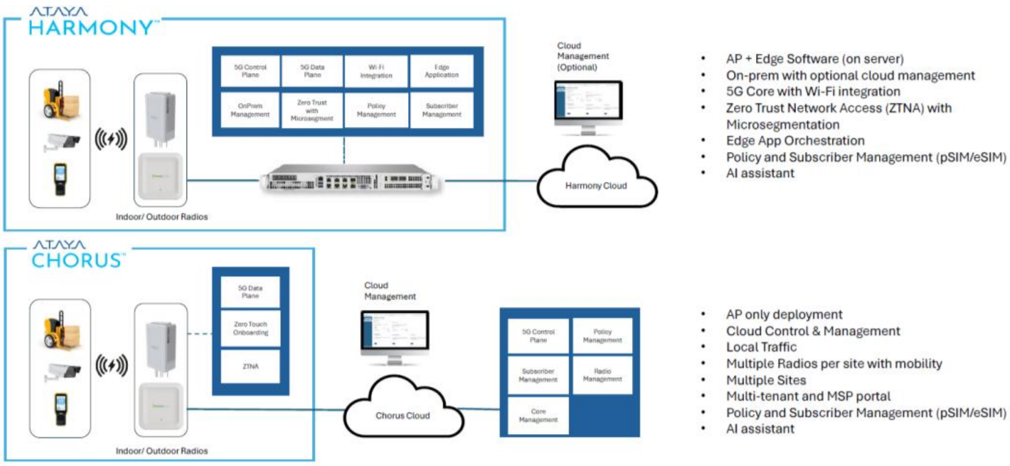

Figure 5. Ataya - Flexible Deployment Choices with Harmony and Chorus

Similarly, ITRI's O-RAN-based Athena orchestrator enables open, multi-vendor integration of network and AI components. These solutions point to the future of smart manufacturing—AI-empowered, cloud-edge-coordinated, and security-assured platforms that enhance operational efficiency, flexibility, and supply chain resilience.

Supply Chain Resilience via 5G and Smart Connectivity

A resilient supply chain must endure disruptions and recover swiftly, and 5G offers powerful tools to achieve this. On the factory floor, 5G's high bandwidth, low latency, and reliable connectivity enable real-time coordination across automation systems—outperforming traditional Wi-Fi, which often suffers instability and latency in industrial settings.

Dedicated 5G networks maintain robust communication even in noisy, device-dense environments, ensuring deterministic performance. For example, if a defect is detected, machines can instantly halt production via 5G, preventing large-scale quality issues. Likewise, production data can be shared across sites in real time to rebalance capacity when market conditions shift.

5G and IoT together empower flexible manufacturing and cross-site collaboration. Private 5G connects vast numbers of devices wirelessly, allowing rapid reconfiguration of production lines without fixed cabling. This agility shortens product changeovers and accelerates adaptation to new requirements. Cloud-connected 5G networks also link geographically dispersed factories: sites can share inventory data and shift production during disruptions, while experts can troubleshoot remotely using AR and high-definition video. Such instant collaboration enhances adaptability and reduces downtime.

Japan's manufacturing experience illustrates this transition. ITOCHU Techno-Solutions Corporation shows that a XGMF (XG Mobile Promotion Forum) survey found 65% of manufacturers dissatisfied with factory network reliability, citing Wi-Fi instability and interference. As a result, many are adopting 5G and Wi-Fi 6 to boost coverage, device density, and reliability. Nearly half plan hybrid deployments combining both technologies to enhance redundancy.

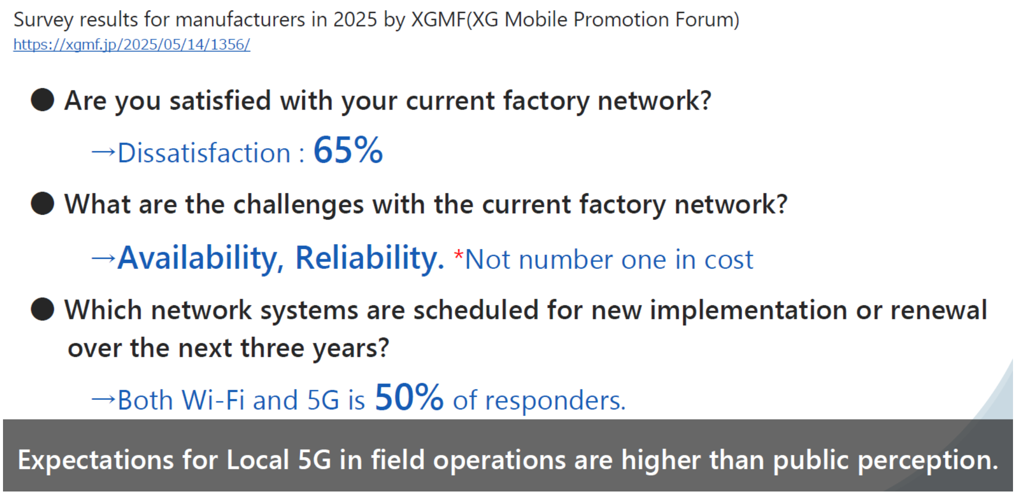

Figure 6. CTC - Flexible Deployment Choices with Harmony and Chorus

Although early skepticism existed, pilot programs and use cases—such as stable communication for unmanned vehicles and automated lines—are proving 5G's value. With deregulation supporting "Local 5G" networks, adoption is accelerating. A robust 5G backbone is now seen as essential to ensure stable operations, faster recovery, and stronger supply chain resilience.

Smart manufacturing is harnessing 5G, AI, and cloud computing to build more sustainable and resilient supply chains. Strengthened cybersecurity ensures secure digital infrastructure, while AI enhances automation and decision-making across operations. 5G's high-speed, low-latency connectivity enables real-time collaboration from factory floors to global networks.

Together, these technologies form an integrated foundation: secure networks protect data, AI drives intelligent optimization, and 5G links all elements seamlessly.

This triad enables supply chains to adapt swiftly to disruptions, reduce resource waste, and align with long-term sustainability goals.

4.3 Promoting Innovation in Smart Manufacturing Applications through Digital Transformation

Session III of the 2025 APEC seminar examined how digital transformation, underpinned by private 5G networks, AI, and industrial IoT, is accelerating innovation in smart manufacturing across Asia. Drawing from the experiences of Singapore's Tam Yao Technologies and Chinese Taipei's Wave Communications, Metal Industries R&D Center (MIRDC), and the Market Intelligence & Consulting Institute (MIC), the session showcased how next-generation networks are catalyzing industrial renewal. Singapore's Manufacturing 2030 Roadmap and economy-wide 5G coverage illustrate the power of coordinated policy, infrastructure investment, and public–private collaboration in creating an environment where intelligent manufacturing can thrive.

Meanwhile, Chinese Taipei's private 5G development reflects a pragmatic and application-driven approach, with more than one hundred projects approved since 2022. These initiatives—including the integration of AI-enabled inspection systems in automotive LCD panel manufacturing and the deployment of a 5G-AIoT smart shipyard by Wave Communications and China Ship Building Corporation (CSBC) — demonstrate that digital transformation is becoming a key driver of competitiveness and sustainability. Across all case studies, the message was clear: the convergence of 5G and AI is turning traditional production systems into dynamic, data-driven ecosystems capable of real-time optimization and predictive decision-making. To sustain this progress, both Singapore and Chinese Taipei must address persistent obstacles such as high costs, limited digital talent, and system-integration complexity, while leveraging emerging Network-as-a-Service (NaaS) business models to lower adoption barriers.

The session concluded that innovation in smart manufacturing is not solely about deploying advanced technologies but about orchestrating an ecosystem where infrastructure, intelligence, and institutions reinforce one another. Governments, enterprises, and research institutes must work in tandem to establish digital resilience, promote experimentation, and scale AI-driven transformation. Through such synergy, private 5G will not only enhance industrial efficiency and quality but also shape a more sustainable, adaptive, and competitive manufacturing future for the Asia-Pacific region.

Building the Foundations of Smart Manufacturing through Digital Connectivity

As a global logistics and technology hub, Singapore has leveraged its

Manufacturing 2030 Roadmap to position itself as a leader in smart and sustainable production. The government's goal—to raise manufacturing value-added by 50 percent within the decade—relies heavily on digital transformation across semiconductors, precision engineering, and clean-energy manufacturing. The Economy / Singapore 95 percent 5G outdoor coverage, complemented by an economy-wide fiber backbone and localized edge computing, provides an enabling foundation for real-time industrial automation.

Figure 7. Tam Yao Technologies – Why does Singapore need Smart Manufacturing

Case studies from Tam Yao Technologies illustrated this transformation in action. The company highlighted collaborative projects such as Micron's 5G-enabled semiconductor fab and the Hyundai Electric Vehicle Innovation Center, both of which integrate private 5G networks with edge analytics and AI-based quality control. These facilities operate digital-twin environments—virtual replicas of physical production systems—allowing engineers to simulate, monitor, and optimize performance continuously. AI algorithms perform predictive maintenance and defect detection, ensuring operational stability while minimizing waste and energy consumption. This digital connectivity model, supported by Singapore's Infocomm Media Development Authority (IMDA) and Agency for Science, Technology and Research (A*STAR), Technology and Research, exemplifies a government–industry–research partnership that aligns infrastructure deployment with innovation goals. Singapore's success underscores that digital transformation in manufacturing is as much about governance and coordination as it is about technology.

In contrast, Chinese Taipei's trajectory demonstrates a growing but differentiated ecosystem. According to MIC's 2025 Chinese Taipei Enterprises' Adoption Research of Private 5G Networks, more than 117 private 5G projects had been approved by mid-

2025, with manufacturing representing over 30 percent of total deployments. This expansion reflects the growing recognition that resilient digital infrastructure is essential for competitiveness. Manufacturers in Chinese Taipei face familiar challenges—ranging from aging wired networks to limited automation—but are increasingly turning to private 5G for solutions. Yet MIC's research found that while 84 percent of companies reported network constraints, only 25 percent planned to upgrade their systems soon, constrained by high deployment costs and a shortage of technical personnel. These findings reveal an urgent need for more ecosystem-level coordination, targeted subsidies, and workforce development to ensure that private 5G's potential translates into measurable productivity gains.

Demonstrating Innovation through Real-World Industrial Transformation

Two flagship case studies of Chinese Taipei illustrated how 5G and AI integration is transforming traditional manufacturing into intelligent, data-centric operations. The first, presented by MIRDC, detailed a collaboration with a local enterprise to introduce 5G-enabled AI analytics into automotive LCD panel production. Within a clean-room environment, MIRDC deployed small-cell base stations to create a secure, low-latency private 5G network with uplink speeds exceeding 400 Mbps. This network supported the transmission of high-frequency vibration and imaging data from the cutting and lamination stages of panel manufacturing. Using an unsupervised learning algorithm—One-Class Support Vector Machine (OCSVM)—the system analyzed sensor data to detect anomalies and predict tool wear before it caused product defects.

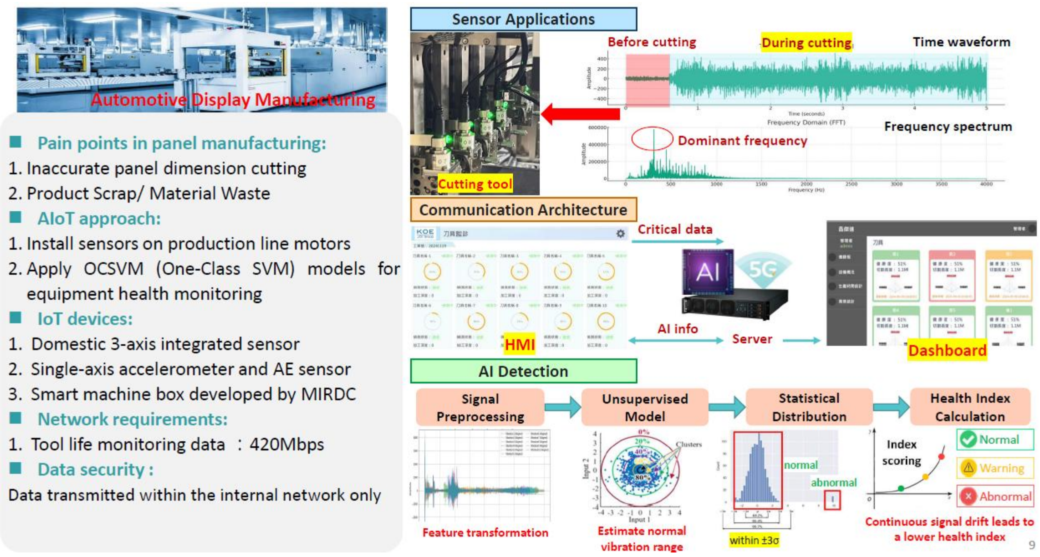

Figure 8. MIRDC – Smart Manufacturing – Equipment Monitoring for Automotive LCD Panel Production

In addition, AI-based computer vision inspected polarizer alignment in real time, replacing manual microscope-based sampling with fully automated image recognition. A centralized dashboard integrated equipment status, electricity consumption, and water-pump performance data, enabling remote monitoring and energy optimization. The results were striking: improved yield rates, fewer product defects, and reduced electricity usage. MIRDC emphasized that the project not only improved efficiency but also supported environmental sustainability by cutting carbon emissions. The case demonstrated how 5G's high bandwidth and low latency make it possible to coordinate thousands of sensors and AI models simultaneously, turning factories into adaptive ecosystems capable of continuous learning and optimization.

The other case, introduced by Wave Communications, focused on the company's partnership with CSBC Corporation, Chinese Taipei's largest shipbuilder, to establish a next-generation smart shipyard. Spanning more than 70,000 square meters, the site integrated 11 to 13 high-power 5G base stations to connect cranes, drones, and digital command centers. Engineers could visualize ship-hull designs via 3D digital twins, overlaying live construction data to monitor progress and detect deviations. Augmented reality (AR) tools enabled seamless communication between engineers and operators, reducing the time required for inspections and minimizing human error.

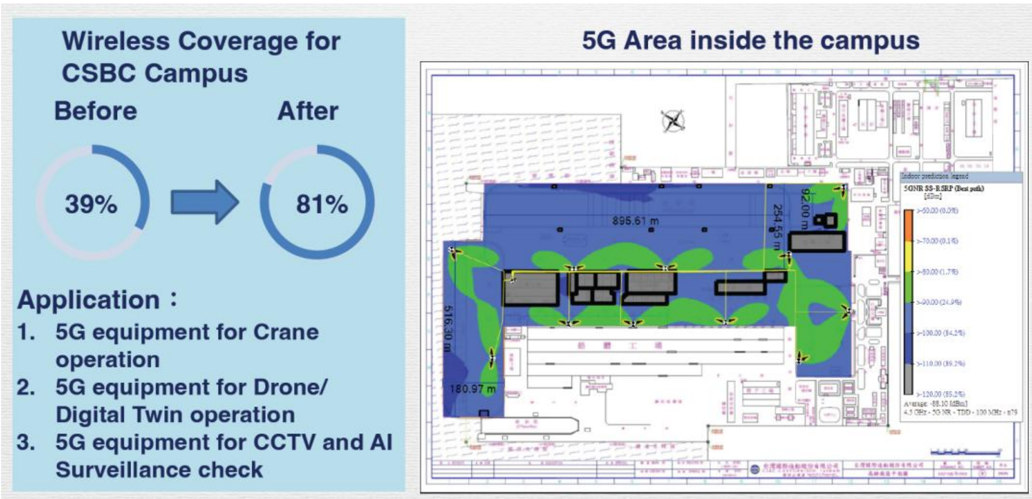

Figure 9. Wave Communications – Use P5G as a CSBC wireless infrastructure for next decade of Digital Transformation

AIoT applications enhanced safety and logistics: the system monitored gas concentration, tracked crane movements, and optimized material storage and retrieval. Unlike Wi-Fi networks—which suffer interference and limited coverage in metallic industrial environments—the private 5G network provided reliable, wide-area connectivity essential for heavy industry. Wave Communications designed the infrastructure with scalability in mind, anticipating future expansion into AI-driven navigation, remote diagnostics, and automated docking systems. The project marked Chinese Taipei's first large-scale maritime 5G implementation, demonstrating that private networks can support mission-critical applications in complex, high-risk settings. Together, MIRDC's initiative and Wave's shipyard project exemplify how private 5G transforms both precision manufacturing and large-scale heavy industries—bridging innovation from microelectronics to maritime engineering.

Integrating AI, Ecosystem Collaboration, and New Business Models

Across all discussions, a consistent theme emerged: smart manufacturing innovation hinges on the convergence of connectivity, intelligence, and collaboration. MIC's survey found that over 80 percent of enterprises using private 5G have already deployed AI applications, including image recognition, worker-behavior analysis, predictive maintenance, and safety monitoring. This integration allows manufacturers to move beyond reactive management toward real-time, data-driven optimization. Edge computing processes immediate tasks—like robotic movement or visual inspection—while the cloud handles large-scale analytics and digital-twin simulations. Private 5G ensures that these layers communicate seamlessly, creating feedback loops where production decisions are made dynamically based on live data.

However, achieving this level of transformation requires overcoming cost and complexity barriers. High deployment and maintenance expenses remain the most cited challenge, especially for small and medium-sized enterprises. To address this, global vendors such as Ericsson, Nokia, and Cisco have begun offering cloud-native, subscription-based Network-as-a-Service (NaaS) models. These solutions convert traditional capital expenditure into flexible operational expenditure, allowing companies to scale their networks as needed. With unified management, multi-standard integration, and plug-and-play industrial applications, these platforms reduce integration costs and technical hurdles. For manufacturers, NaaS represents a practical bridge to digitalization—lowering financial risk while accelerating the adoption of AI-enabled automation.

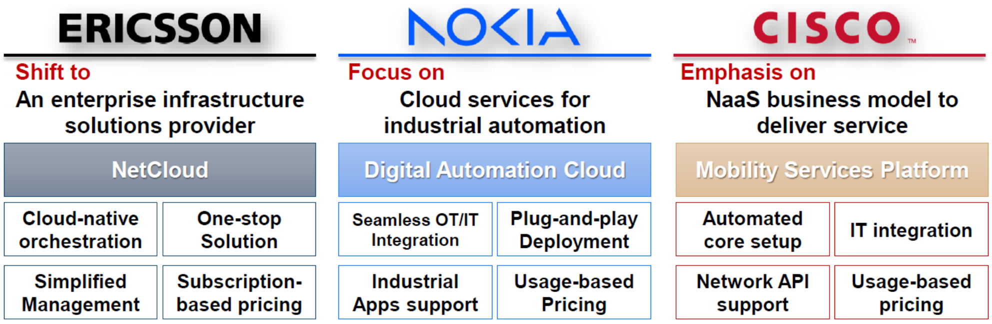

Figure 10. MIC – Private 5G as a Service to Lower Barriers for Adoption

Government support further reinforces these efforts. In Singapore, IMDA and A*STAR continue to fund 5G testbeds, support SME participation, and develop standards for AI-driven manufacturing. In Chinese Taipei, MODA and its Private 5G Office play a pivotal role in coordinating spectrum allocation, promoting public–private test sites, and nurturing talent development through research partnerships. The synergy among policy frameworks, industrial initiatives, and vendor strategies creates a self-reinforcing ecosystem for digital innovation.

In conclusion, digital transformation in manufacturing is no longer an aspirational goal but an ongoing process that requires strategic alignment between technology, people, and policy. Private 5G functions as the digital nervous system connecting machines and data; AI serves as the cognitive engine driving real-time optimization; and new service-oriented business models ensure scalability and inclusivity. Together, these forces are reshaping manufacturing into an intelligent, adaptive, and sustainable enterprise. Through continuous collaboration and innovation, both Singapore and Chinese Taipei are positioned to lead the next phase of global industrial evolution—where smart manufacturing becomes not just a competitive advantage but a defining characteristic of modern economic resilience.

4.4 Summary

Based on insights shared by experts across the three sessions of the two-day seminar, it is clear that 5G is propelling manufacturing into a new era of intelligence and resilience. Private 5G (NPN) networks—with high bandwidth, low latency, and strong security—overcome the limitations of legacy wired and Wi-Fi systems, enabling applications such as AI-based visual inspection, autonomous robots, digital twins, and remote maintenance. These advancements have boosted production efficiency and equipment effectiveness by 15–20%. Combined with edge computing and network slicing, 5G enables real-time analytics, ensures data sovereignty, and enhances operational agility.

The deployment of 5G also reshapes cost structures and strengthens supply-chain resilience by reducing downtime and labor costs, improving energy efficiency, and supporting cross-site collaboration and real-time decision-making. Through AI and cloud-edge collaboration, manufacturers achieve predictive maintenance, intelligent scheduling, and improved product quality—building a more autonomous and sustainable industrial ecosystem.

In essence, 5G serves as the digital nervous system of smart manufacturing, while AI acts as its cognitive engine. Together, they are redefining productivity, sustainability, and global competitiveness across the APEC manufacturing landscape.

5. Analysis of 5G technology in smart manufacturing Issues: Resilient, Sustainable, and Intelligent Growth

Global manufacturing is undergoing a profound structural transformation that extends beyond technology to encompass industrial organization and governance. Confronted with geopolitical realignments, energy-price volatility, and accelerating carbon-neutrality commitments, economies now recognize that industrial competitiveness must evolve from a narrow focus on efficiency toward a model that balances resilience, security, and sustainability. The primary catalyst for this shift lies in the convergence of 5G, AI, cloud-edge computing, and digital-twin technologies, which are redefining both the flow of information and the logic of value creation across supply networks.

The two-day APEC 5G Smart Manufacturing Seminar brought together experts from Japan; Republic of Korea; Chinese Taipei; Singapore; the United States, and several other member economies. Discussions were organized around three interrelated themes:

- Panel 1: 5G-Enabled Smart Manufacturing -Driving Industrial Transformation.
- Panel 2: Leveraging Smart Manufacturing to Create Sustainable and Resilient Supply Chains.
- Panel 3: Promoting Innovation in Smart Manufacturing Applications through Digital Transformation.

Across these three panels, participants examined the issue from technical, industrial, and policy perspectives — covering 5G Private Networks, AI, and Digital Twins on the technology side; productivity, resilience, and ESG on the industry side; and spectrum policy, business models, and cross-sector collaboration on the policy side. Collectively, the sessions revealed a clear paradigm shift: 5G and AI are propelling manufacturing from an efficiency-driven model toward an ecosystem defined by resilience, sustainability, and innovation.

This transition is not a linear process driven by technology alone but a multi-layered transformation of industrial systems. When 5G serves as the connectivity layer linking AI, cloud, and digital-twin applications, the fundamental logic of production is rewritten: information flows replace physical flows as the core of productivity, and data governance supersedes cost control as the basis of competitiveness.

The consensus emerging from the seminar was clear — future industrial leadership will depend on an economy's capacity for data intelligence and cross-domain interoperability, rather than on process efficiency alone. In this sense, 5G is not merely a network upgrade; it marks the beginning of a re-organization of the global manufacturing ecosystem and a redistribution of industrial value.

5.1 5G as the Technological Foundation and Value Reconfiguration

In Panel 1, Private 5G Networks were recognized as the foundational infrastructure for smart manufacturing. Speakers emphasized that 5G's high reliability, ultra-low latency, and enhanced security make it the nervous system linking AI, robotics, sensor networks, and cloud analytics. Ms. Hwang Kyusoon from Republic of Korea's 6G Forum noted that Republic of Korea manufacturers are rapidly deploying private 5G to replace Wi-Fi and wired connections — not merely as a connectivity upgrade but as a systemic reconfiguration that enables real-time closed-loop management of production, maintenance, quality, and energy use.

Mr. Cy Feng of PEGATRON explained that greenfield factories built around 5G architecture can achieve end-to-end visibility and data integration, transforming operations from human-supervised control to autonomous intelligence. For brownfield facilities, however, integration costs and workforce reskilling remain key challenges. Success, he stressed, depends less on technical sophistication than on clarity of objectives and phased ROI strategies — underscoring that digital transformation is a process of progressive investment rather than a single technological leap.

Mr. Sudhansu Dora of Mavenir highlighted that regulatory fragmentation remains the chief obstacle to private 5G deployment. Divergent spectrum policies and equipment standards have limited economies of scale. He advocated for a Federated Spectrum Model to harmonize allocations across economies and lower entry barriers for SMEs. Dr. Chung-Yung Chia from Chunghwa Telecom presented Chinese Taipei's tiered deployment approach: dedicated core networks for large manufacturers, shared core models for medium-sized firms, and operator-managed services for SMEs. This flexible architecture demonstrates how policy design can translate technological potential into inclusive adoption.

Taken together, these discussions position Private 5G as a general-purpose enabling technology for industry. Beyond connectivity, it creates a secure and scalable environment for AI, edge computing, and digital-twin integration. As manufacturing processes become data-driven and decision-making increasingly automated, a firm's core assets will shift from physical equipment to data sovereignty and algorithmic capability — signaling a fundamental reconfiguration of industrial value.

5.2 AI and Digital Twin Integration — From Automation to Autonomy

The fusion of AI and digital-twin technologies represents the conceptual heart of next-generation smart manufacturing. Speakers agreed that AI is evolving from an analytical tool into a learning engine for decision-making. When combined with 5G's real-time data transmission, manufacturing systems can achieve millisecond-level predictive response and self-optimization.

Cases from Mavenir and PEGATRON demonstrated that AI-based predictive maintenance can drastically reduce unplanned downtime while optimizing traffic flows and energy usage. These applications illustrate a broader organizational shift: decision-making authority is moving from human supervisors to intelligent systems, transforming enterprises from reactive operators into proactive learners.

Mr. Feng further observed that the digital twin is the nexus of this transformation. By mirroring physical assets within a virtual simulation environment, it enables continuous testing, forecasting, and optimization before deployment. Through 5G's low-latency feedback, virtual decisions can be instantly applied to physical operations, creating a self-reinforcing learning loop between model and reality. Factories thus evolve from reactive to predictive and ultimately adaptive systems.

At a conceptual level, the AI-Digital Twin convergence represents a redefinition of industrial rationality. Traditional manufacturing relied on human experience and judgment; intelligent manufacturing relies on data-driven inference. This paradigm elevates decision precision and transfers knowledge accumulation from individuals to systems. In this sense, AI and Digital Twin integration is not merely enhancing efficiency but ushering in a new era of cognitive industry, where machines and networks learn, predict, and adapt in real time.

5.3 Smart Manufacturing and Supply-Chain Resilience — A Symbiotic Relationship

Panel 2 extended the discussion beyond factory-level optimization to the broader resilience of global supply chains. The central question was how smart manufacturing can serve as the infrastructure for resilient value networks.

Dr. Wen-Yuh Jywe of the NTU observed that today's supply-chain disruptions are no longer isolated events but systemic shocks triggered by geopolitical tensions, pandemics, and climate events. Resilience now depends on the ability to detect, predict, and reconfigure operations dynamically. Smart manufacturing provides this structural capability through IoT sensing and real-time data flows that enable end-to-end visibility and AI-based risk prediction.

Mr. Jack Hu from Trend Micro emphasized that as OT and IT systems converge, supply-chain resilience is inseparable from cyber resilience. Increased connectivity expands the attack surface, making proactive defense and threat intelligence indispensable. AI-driven security frameworks must therefore be integrated into manufacturing ecosystems to safeguard data integrity and operational continuity.

Participants further highlighted that governance and policy frameworks are as critical as technology. When governments establish open-data platforms and cross-sector collaboration mechanisms, firms can share logistics and production data under common standards and simulate disruption scenarios via Digital Twins. This transforms resilience from an individual firm's attribute into a collective capacity embedded within industrial ecosystems.

From a global perspective, smart manufacturing thus shifts the governance logic of supply chains from efficiency maximization to risk balancing. Resilience becomes a designed, measurable, and continuously optimized function — a hallmark of industrial systems prepared for an era of permanent uncertainty.

5.4 Integrating Digital and Green Transformation — From Efficiency to Sustainability

Panel 3 illuminated how digitalization and green transition have become mutually reinforcing drivers of industrial renewal. The focus of smart manufacturing is no longer confined to efficiency gains; it now anchors the global movement toward sustainable production and net-zero transformation. As carbon-pricing regimes and green-supply-chain audits proliferate worldwide, manufacturers face the dual imperative of maintaining competitiveness while meeting environmental obligations.

Mr. Kun-Cheng Huang from the Metal Industries R&D Centre explained that the combination of 5G connectivity and AI analytics enables real-time energy-management systems capable of monitoring consumption and optimizing performance at the machine level. High-frequency sensor data, transmitted through 5G, allow predictive energy scheduling that minimizes waste and converts carbon output into measurable, traceable information assets. In doing so, enterprises transform compliance into operational intelligence.

A representative from King Jet Tech added that digital transparency is also redistributing power within global supply chains. Whereas ESG verification once remained the privilege of large firms with dedicated reporting capacity, 5G and cloud-based monitoring now permit SMEs to feed energy and emission data directly into shared platforms, participating in green co-governance. This “data democratization” narrows informational asymmetries between tiers of suppliers and strengthens overall ecosystem accountability.

Dr. Wen-Jye Huang of Wave-In Communication presented a compelling maritime example: by integrating Private 5G networks with LEO satellite links aboard container ships, AI systems can dynamically adjust routes according to real-time meteorological and oceanic data, reducing fuel consumption and emissions. The case demonstrates that the green potential of 5G extends well beyond factories into logistics and transport, forming a technological backbone for low-carbon economies.

Collectively, these discussions signal a paradigm shift from “digital for efficiency” to “digital for sustainability.” 5G’s high-reliability, low-latency architecture turns ESG management from a retrospective reporting exercise into an algorithmic process of optimization. “Green by Digital” is thus emerging as a defining principle of modern industrial governance.

5.5 Business Models and Inclusive Innovation

The diffusion of smart manufacturing hinges not only on technological maturity but also on viable economic models. As the capital intensity of 5G, AI, and Digital Twin solutions remains high, innovative approaches are needed to bridge the affordability gap — particularly for SMEs.

Dr. Huang emphasized that scaling 5G cannot rely solely on large-enterprise deployments. Instead, ecosystems jointly developed by telecommunications operators and system integrators can deliver Network-as-a-Service (NaaS) and subscription-based offerings that lower entry barriers. Operators bring network stability and cybersecurity competence at the CT layer, while integrators focus on OT/IT integration and domain-specific applications. Their collaboration transforms high-complexity technologies into modular, service-oriented products.

Singapore-based Alex Wu noted that subscription-driven adoption allows companies to embark on a "rent-before-build" digital journey, testing return on investment through incremental scaling. This model is particularly beneficial for SMEs, turning smart manufacturing from a fixed-asset investment into a recurring-service model (OPEX rather than CAPEX).

Two structural implications arise. First, the transition from ownership to access accelerates the servitization of technology, enabling manufacturers to upgrade physical operations through software-driven cycles. Second, it redistributes risk within the ecosystem: suppliers share operational and technological responsibilities, allowing clients to focus resources on innovation and market agility.

For policymakers, this implies a shift from subsidizing hardware procurement toward facilitating market ecosystems. Governments can foster open testbeds, standardized API interfaces, and shared-spectrum frameworks to nurture service-based digital infrastructure. In the long run, the competitiveness of smart manufacturing will depend less on technological prowess than on the inclusiveness and adaptability of its business architecture.

5.6 Multi-Site Resilience and Cross-Border Collaboration

As global supply chains become increasingly decentralized, multi-site resilience is emerging as the defining strategy for navigating uncertainty. Moderator Dr. Chun-Hui Hung observed that the post-pandemic industrial landscape is characterized by regional diversification rather than consolidation. Manufacturers are prioritizing redundancy, flexibility, and local responsiveness over singular efficiency.

Alex Wu's concept of a Resilient Digital Twin Network offers a structural solution. By combining IoT data and AI-based simulations, firms can construct digital replicas of geographically distributed facilities, achieving real-time scheduling, energy balancing, and predictive maintenance across borders. When disruptions occur at one site, production can be automatically reallocated to others, ensuring operational continuity. This architecture turns resilience into a design principle rather than a contingency plan.

Dr. Huang underscored that true resilience lies in technological synergy rather than mere redundancy. AI, robotics, satellite communications, and cloud-edge coordination must operate as an integrated portfolio — a framework of "technology-portfolio governance." Only through multi-layer integration can firms reconcile efficiency, cost, and security in a volatile global environment.

Comparative international experiences further highlight that industrial resilience is deeply intertwined with policy orientation. While the EU's "Open Strategic Autonomy" and the U.S. CHIPS Act emphasize technological self-reliance, Asian economies increasingly pursue regional interoperability and shared standards to balance sovereignty with efficiency. In this context, smart manufacturing serves as the connective tissue of globalization's next phase — enabling decentralized production networks that remain collectively coordinated.

5.7 Policy Insights and Global Implications

Across the three panels, a coherent global narrative emerges: manufacturing is entering an era defined by intelligence, sustainability, and openness. The integration of 5G and AI is reconfiguring industrial division of labor, making data flow a core production factor and altering the basis of competitive advantage.

From a policy standpoint, several imperatives stand out. First, cross-border coordination of spectrum and standards is essential. A harmonized framework for industrial 5G bands and certification would enable scalable private-network deployment and accelerate the evolution of open ecosystems such as Open RAN and AI-RAN.

Second, governments should advance the Digital × Green Manufacturing framework, positioning 5G as critical infrastructure for energy optimization and carbon-data interoperability. When carbon metrics become traceable and comparable, sustainability will evolve from a regulatory cost into an innovation driver.

Third, inclusivity must remain central to digital industrialization. Without equitable access to technology and skills, SMEs risk exclusion from next-generation supply chains. "Resilience Accelerator" initiatives, modular solution packages, and targeted talent programs can help bridge these divides. The goal is to ensure that smart manufacturing strengthens — rather than fragments — the broader economic fabric.

Ultimately, the competitive frontier will shift from technological speed to institutional coherence and ecosystem connectivity. Economies that can balance openness with security, and innovation with governance, will define the next stage of industrial leadership.

5.8 Summary— Toward a New Global Industrial Order

Viewed through the lens of global development, the evolution of smart manufacturing represents a transformation of industrial civilization itself. The value of 5G lies not merely in faster connectivity but in redefining connection — turning data into energy and endowing factories with situational awareness and autonomous decision-making.

The value of AI lies in embedding knowledge into algorithms, enabling organizations to learn and adapt continuously. The value of Digital Twin technology lies in creating a mirrored space where the physical and digital worlds interact, allowing policies, technologies, and markets to be simulated and refined before real-world execution.

Together, these shifts constitute a new industrial order in which competitiveness is determined less by scale or cost than by data intelligence, energy efficiency, and governance agility. Manufacturing systems will evolve from production networks into living ecosystems that integrate environment, energy, and information in real time.

The ultimate goal of smart manufacturing, therefore, is not simply automation or digitization, but the creation of an open, self-aware, and self-healing industrial system — one capable of learning continuously, responding instantly, and coexisting sustainably with its environment. Such a system will form the resilient core of the global economy in an age of uncertainty and define the contours of the next industrial civilization.

6. Conclusion

This APEC-funded project has successfully achieved its primary objective of identifying innovative 5G applications that enhance interoperability between manufacturing systems and 5G networks, thereby strengthening efficiency, resilience, and sustainability across supply chains in the APEC region.

Through comprehensive discussions across all sessions and panels during the two-day seminar, complemented by pre-event survey findings, the project confirmed that 5G-enabled smart manufacturing is no longer conceptual but operational. Both advanced manufacturing economies. Such as Japan, Republic of Korea, and Singapore and emerging production bases. Including Chile; the Philippines; and Thailand demonstrated a shared recognition that digital transformation is a prerequisite for maintaining competitiveness and supply chain stability. While readiness levels vary, common priorities over the next five years consistently include 5G connectivity deployment, AI integration, and digital talent development.

Importantly, the project successfully identified and validated several innovative 5G-enabled applications that improve interoperability between manufacturing processes and communication systems. These include:

- Deployment of 5G Non-Public Networks (NPNs) to ensure secure, low-latency industrial connectivity;
- AI-powered visual inspection and predictive maintenance systems integrated via 5G infrastructure;
- Digital twin platforms enabling real-time production optimization and cross-system coordination;
- Network-as-a-Service (NaaS) models that lower entry barriers and expand SME participation.

Case studies presented during the seminar demonstrated measurable outcomes, including 15–20% improvements in production and energy efficiency, enhanced data security, reduced operational costs, and strengthened environmental performance. These results confirm that the convergence of 5G, AI, and digital twin technologies is effectively redefining productivity and resilience across the industrial value chain.

The discussions further underscored that 5G represents not merely a technological upgrade but a systemic transformation of industrial organization. 5G functions as the digital nervous system of the factory, enabling real-time data flow; AI acts as the cognitive engine driving adaptive decision-making; and digital twins provide a mirrored environment for simulation, optimization, and governance experimentation. Together, these technologies establish the foundation for intelligent, interconnected, and sustainable industrial ecosystems.

Nevertheless, structural challenges remain. High deployment costs, integration complexity, and digital talent shortages continue to limit broader adoption, particularly among SMEs. Addressing these constraints requires coordinated action among government, industry, and academia, reinforcing the importance of the triple-helix model highlighted throughout the seminar.

Policy Recommendations and Future Cooperation

As the principal policy outcome of this project, the following recommendations are proposed for consideration by APEC member economies and the PPSTI:

1. **Promote Cross-Border Spectrum and Standards Harmonization**
   Member economies are encouraged to advance coordination on industrial 5G spectrum allocation, certification mechanisms, and interoperability standards. Harmonized frameworks will facilitate scalable private-network deployment and support the evolution of open ecosystems such as Open RAN and AI-RAN.
2. **Advance the "Digital × Green" Manufacturing Framework**
   APEC economies should position 5G as critical infrastructure for carbon intelligence, energy optimization, and sustainability reporting. By enabling interoperable carbon-data systems, digital infrastructure can transform sustainability from regulatory compliance into an innovation driver.
3. **Ensure Inclusive Digital Industrialization**
   Targeted support mechanisms—including shared testbeds, modular solution packages, SME-focused financing models such as NaaS, and dedicated digital talent programs—should be expanded to prevent technological exclusion and ensure equitable participation across economies, including women professionals and SMEs.
4. **Strengthen Regional Collaboration Platforms**
   Future cooperation under the PPSTI framework may include cross-border pilot projects, joint certification initiatives, talent exchange programs, and structured knowledge-sharing platforms to scale best practices and accelerate collective learning.

In conclusion, this project confirms that smart manufacturing represents more than incremental digital efficiency; it signals a transition toward a new industrial paradigm characterized by intelligence, openness, and sustainability. By aligning technological innovation with policy coherence and inclusive governance, APEC member economies can jointly build an interconnected industrial ecosystem that is self-learning, adaptive, and resilient.

Such coordinated advancement will not only strengthen regional supply chains but also define the next stage of global industrial development in an era marked by uncertainty and rapid technological change.

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