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Research on the pathways and spatial support mechanisms for industry–innovation integration across upstream, midstream and downstream of the intelligent connected vehicle industry in urban agglomerations—a case study of Tesla (Shanghai)

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Abstract. The intelligent connected vehicle (ICV) industry is the core arena for the integration of the "automotive industry + digital technologies," and the integration of industry and innovation is key to enhancing the sector's competitiveness. Taking Tesla (Shanghai) as the study sample, this paper investigates the pathways of industry–innovation integration in the ICV sector within an urban agglomeration and the spatial support mechanisms that enable it. The study finds that Tesla (Shanghai) achieves industry–innovation integration through the following pathways: (1) staged transformation of R&D focus; (2) upstream firms building R&D bases to strengthen their autonomous core-technology capabilities; (3) construction of localized, vertically integrated supply-chain networks; and (4) realizing industry–innovation coordination through diversified collaboration and standards alignment, thereby expanding brand influence and generating network effects. The paper concludes that Tesla (Shanghai), by establishing the Shanghai Gigafactory as a spatial carrier, has formed a hierarchical distribution of supply chains and a pattern of regional division of labor across "Shanghai—the urban agglomeration—the nation," and has made full use of the multidimensional support mechanisms such as preferential policies in the Lingang New Area to drive industry–innovation integration. Finally, the paper offers policy, corporate, and spatial-level lessons for urban agglomerations aiming to develop ICV industry clusters.

Keywords: urban agglomeration, industry–innovation integration, intelligent connected vehicle industry

1. Introduction

As a hallmark industry resulting from the deep integration of "automotive manufacturing + digital technologies," the intelligent connected vehicle (ICV) sector has become the core track of global manufacturing transformation and an important strategic focus of national technological competition. The ICV industry chain spans upstream core components such as chips and LiDAR, midstream intelligent vehicle manufacturing, and downstream vehicle-to-infrastructure cooperation and intelligent mobility services, while relying heavily on cross-domain technologies such as AI, 5G, and big data. Its development will directly affect the upgrading and intelligentization of national manufacturing [1]. At present, global competition in the ICV field has shifted from mere technological breakthroughs to a comprehensive contest of industrial-chain ecosystems and innovation systems, and industry–innovation integration has become an important criterion for measuring an industry's core competitiveness. Against this background, China—the world's largest automobile producer and consumer market—is accelerating industrial transformation through the dual drives of "electrification" and "intelligentization," and Tesla (Shanghai) serves as an ideal case for studying the evolution of the ICV industry chain and parsing the mechanisms of industry–innovation integration.

Since locating in the Lingang New Area of Shanghai in 2018, Tesla's Shanghai plant has achieved successive annual production-capacity milestones, spurring the agglomeration of core suppliers in the Yangtze River Delta, and bringing a large number of domestic Chinese firms into Tesla's supply-chain system, thus forming a closed-loop industry chain from key component R&D to after-market services. By building an R&D center that houses multiple specialized laboratories, Tesla (Shanghai) has independently completed innovations such as electronic component simulation systems and optimizations of intelligent-driving algorithms, thereby shaping a development pathway in which innovation drives production transformation and realizing industry–innovation integration. However, existing studies often focus on single dimensions—for example, Tesla's supply-chain characteristics or innovation trajectories—and have not systematically unpacked the fusion logic of manufacturing and innovation, particularly lacking analyses of how spatial layout and policy instruments support industry–innovation integration [2-4]. Therefore, an in-depth analysis of Tesla (Shanghai)'s industry–innovation integration pathways can help fill current research gaps and provide practical lessons for urban agglomerations seeking to build ICV industry clusters.

2. Development status of Tesla (Shanghai)

As a key hub in Tesla's global strategy, Tesla (Shanghai) Co., Ltd. has formed an industrial structure driven by the dual engines of "electric vehicles + energy storage." Its two core facilities—the Shanghai Gigafactory and the Energy Storage Gigafactory—respectively focus on the manufacturing of electric vehicles and components, and the production of electrochemical energy storage systems. As of 2025, the Shanghai Gigafactory has produced more than 3 million vehicles in total, with deliveries in the first eight months of 2024 exceeding 600,000 units—accounting for more than half of Tesla's global deliveries during the same period. It has become Tesla's global export center, with products distributed across Asia-Pacific, Europe, and North America. Moreover, the company has achieved a 95% localization rate for components and a 99.99% localization rate for employees, fully integrating itself into China's industrial chain. This high level of localization and integration gives the case substantial research significance.

3. Development pathways of industry–innovation integration in Tesla (Shanghai)'s intelligent connected vehicle industry

3.1. Transformation of R&D focus: from traditional automobiles to intelligent connected vehicles

According to data from the China Patent Publication System of the National Intellectual Property Administration (http://epub.cnipa.gov.cn/), Tesla has been granted or applied for a total of 247 invention patents, of which 240 were filed between 2016 and 2025. Based on the time of application and the research field, the patents can be categorized as shown in Table 1.

Table 1. Tesla company's invention patents from 2016 to 2025

Year	Total Patents	Related Fields
2016	10	Vehicle body structure and components Motor and electrical systems Seats and interiors
2017	15	Batteries and energy storage Vehicle components and interaction Thermal management systems
2018	27	Batteries and energy storage Foundational intelligent technologies Photovoltaic technology Vehicle body structure and components
2019	18	Materials and manufacturing processes Motor and electrical systems
2020	21	Batteries and energy storage Vehicle body structure and components
2021	14	Batteries and energy storage Motor and electrical systems Lighting and interaction
2022	64	Intelligent driving and data security Batteries and energy storage Electronic components and cooling Vehicle body structure and components

2023	66	Advanced intelligent driving AI and computing technologies Batteries and energy storage Motor and electrical systems Electronics and communications Vehicle body structure and components
2024	4	Batteries and energy storage Vehicle body structure and components
2025	1	Batteries and energy storage

Analyzing Tesla's patent applications from 2016 to 2025, its research and innovation directions in the intelligent connected vehicle (ICV) field can be divided into four stages: the basic function optimization stage (2016–2017), energy technology research and preliminary intelligence exploration stage (2018–2019), intelligent technology breakthrough stage (2021–2022), and full-scenario intelligent technology integration and frontier exploration stage (2023–2025), as shown in Figure 1. Each stage exhibits clear R&D characteristics and presents an overall progressive evolution. During 2016–2017, the innovation focus was on improving vehicle basic component structures, enhancing traditional functional performance, and optimizing early energy-related components, laying a solid hardware foundation for subsequent intelligent connected development. In 2018–2019, while deepening energy storage and management technologies, Tesla began deploying foundational vehicle intelligence technologies. By continuously optimizing battery technology and upgrading charging systems, it achieved breakthroughs in the energy field, while gradually engaging in vehicle positioning, data processing, neural networks, and computational technologies, completing the transition from traditional hardware optimization to "hardware + preliminary intelligence." During 2021–2022, the innovation focus fully shifted to core intelligent driving technologies. By intensively studying autonomous driving path planning and environment perception algorithms, strengthening data security management, upgrading energy and intelligent control systems, and optimizing human–machine interaction, Tesla promoted deep integration of hardware and intelligent functions, enabling the vehicle to leap from "preliminary intelligence" to "advanced intelligence." In 2023–2025, innovation demonstrates characteristics of full-scenario coverage and cross-domain integration. On one hand, Tesla advances autonomous driving toward full-scenario perception and decision-making through enhanced multi-sensor applications and simulation training, while optimizing energy storage systems to achieve diversification and integration. On the other hand, AI algorithms, robotics, and intelligent driving technologies are integrated, and industry-wide vehicle networking standards are promoted to facilitate industrial chain collaboration. From a long-term strategic perspective, Tesla consistently centers its innovation on autonomous driving core technology R&D. Relying on computer vision, machine learning, artificial intelligence, neural networks, and big data, it conducts large-scale independent R&D of autonomous driving systems, continuously building an autonomous driving production network system centered on itself.

Figure 1. Tesla's innovation and R&D trends

3.2. Industry–innovation synergy across the upstream, midstream, and downstream of the industrial chain

Within the intelligent connected vehicle (ICV) industry chain, Tesla has integrated differentiated resources and capabilities across the upstream, midstream, and downstream segments, thereby forming an industry layout that aligns with the developmental needs of urban agglomerations. The structure and operational logic of its industrial-chain deployment exhibit distinct hierarchical characteristics:

(1) Upstream: Building R&D Bases Centered on Innovative Collaboration

In the upstream segment, Tesla does not adopt a broad-based collaboration model; rather, it pursues a dual approach of "deep innovation cooperation with a few enterprises + technological support from innovation platforms." Through substantial resource investment, Tesla focuses on establishing key R&D bases. Among these, the Tesla Shanghai R&D Center, located in the northeastern section of the Shanghai Gigafactory, serves as the critical vehicle for upstream R&D activities. It undertakes vital functions related to the development and breakthrough of core upstream technologies.

(2) Midstream: Innovation in Production Management Driven by Supply-Chain Localization and Vertical Integration

In the midstream segment, Tesla's core strategy revolves around two key dimensions. First, it promotes supply-chain localization to reduce production and logistics costs while improving supply responsiveness. Second, it constructs a vertically integrated "R&D–production" management model, achieving close coordination between innovation and manufacturing processes. This integration not only enhances the efficiency of technological transformation but also strengthens the flexibility and innovativeness of the overall production system.

(3) Downstream: Market Services and Standards Coordination Oriented toward Diverse Collaboration

At the downstream level, Tesla strengthens cooperation with external enterprises to expand its market service capacity—particularly in the domain of data and information services, where it has built a comprehensive collaboration network. In addition, Tesla engages in cooperative discussions and joint development of industry standards with other players in the automotive sector, including competitors. This promotes the refinement of industry technical specifications and supports the establishment of a more orderly industrial development framework.

3.3. Upstream R&D collaboration and independent innovation

An examination of Tesla's 240 patents published between 2016 and 2025 reveals that only two patents from 2018 were related to battery systems developed in collaboration with Panasonic, and one energy storage device patent from 2023 was co-developed with Argonne National Laboratory in Chicago. This indicates that Tesla has developed a strong capacity for independent technological innovation in key manufacturing areas such as battery and energy storage, vehicle assembly, and painting. While early innovations in the upstream and midstream segments relied on cooperative R&D and external supply, Tesla's core battery-technology trajectory clearly shows a transition toward independent R&D and in-house production, culminating in the establishment of a fully autonomous innovation system. By mastering core technologies internally, Tesla has gradually consolidated its leadership in the intelligent connected vehicle sector. Taking the battery field as an example, Tesla initially partnered with Panasonic to build joint production facilities, with both parties dividing production areas and co-designing system architectures [6]. This collaboration simultaneously reduced procurement costs and enhanced Tesla's in-house R&D capability, forming a progressive innovation-conversion model of "procurement/contract manufacturing → collaborative design → independent R&D."

3.4. Downstream technology sharing and standards coordination

To expand the electric vehicle market, Tesla has publicly shared its core patent technologies, developed a unified charging-service network, and lowered access barriers to attract more traditional automakers to transition toward electric vehicles. In 2014, Tesla released a batch of key patents—including those related to battery management and charging systems—allowing other automakers to use them freely. This move significantly reduced R&D and time costs for new entrants, enabling emerging Chinese automakers such as NIO and XPeng to rise rapidly and accelerating the overall development of the EV industry. In November 2022, Tesla disclosed its charging patents and launched the North American Charging Standard (NACS) interface. After being recognized by the Society of Automotive Engineers (SAE), the NACS standard was widely adopted across the industry. Major automakers such as Ford and General Motors joined Tesla's Supercharger network to save on infrastructure construction costs, gradually making Tesla's charging standard the industry mainstream. As more automakers and charging service providers adopted the NACS standard, the total number of NACS-compatible charging stations expanded rapidly, generating a "network effect." The increased availability of charging resources improved user experience, which in turn boosted downstream product sales within Tesla's industrial chain and expanded its revenue streams from charging and related services.

Tesla's initiatives in patent openness and standard coordination have positioned it as both a technological benchmark and a market leader. The widespread adoption of its technologies and standards has guided the direction of industry development, reinforced its market position, and further increased its competitive share in the global electric vehicle market.

4. Support mechanisms for industry–innovation integration in Tesla (Shanghai)'s intelligent connected vehicle industry

4.1. The key spatial carrier for industry–innovation integration: Tesla Shanghai gigafactory

The Tesla Gigafactory is located in the Lingang New Area of Shanghai. On one hand, it leveraged the unique policy and institutional advantages of the new district for rapid establishment and construction, while relying on the Yangtze River Delta's new-energy vehicle industrial ecosystem and supply-chain efficiency. The aggregation of Tesla's vehicle manufacturing has driven the clustered development of upstream and downstream enterprises, reducing production costs and logistics cycles. On the other hand, Shanghai's status as an international shipping hub, together with Lingang's proximity to ports and well-developed expressway network, provides favorable conditions for exporting vehicles and energy-storage products to Asia-Pacific, Europe, and North America.

Table 2. Tesla (Shanghai) Gigafactory feature table

Dimension	Feature
Location Characteristics	Urban-edge development area; transportation hub
Plant Scale	860,000 m²
Plant Elements	Stamping, welding, painting, final assembly main line; die casting, battery & motor production, test track, finished vehicle parking, R&D center and data center, shipping center; office area, cafeteria
Functions	R&D, pilot production, testing, mass production, dining

Within the factory, an on-site R&D center enables internal product design and conversion of design information into production. This ensures that innovative designs are translated into products quickly, accurately, and effectively, exemplifying Tesla's organizational capability in product manufacturing. Located in the advanced manufacturing zone of the Shanghai Free Trade Zone's Lingang New Area, the 860,000 m² plant integrates R&D, production, testing, and office functions, moving beyond traditional factories that focus solely on centralized production or office space. As illustrated in Figure 2, the horizontal layout of the Gigafactory integrates multiple buildings in a straight-line configuration with dual-level vertical production flows for assembly and transportation, minimizing downtime along the production line. Universal robots handle tasks such as body handling, stamping, auxiliary component installation, and painting, reducing labor costs and improving efficiency. Vertically, R&D, management, and production are integrated on-site, with the R&D center, manufacturing lines, and test track collectively enabling the full cycle of "R&D → Manufacturing → Testing → Adjustment". Offices and the data center are directly connected to production lines for timely coordination and scheduling, enhancing production cycle efficiency. Outside the plant, dedicated material transport lanes connect raw materials and components directly to workstations via WOW (Wheel on Work) delivery systems, ensuring high-frequency external transport and short internal transfer distances, thereby reducing logistics distances and saving storage space.

Figure 2. Division of positions for various elements in the factory area(base map source: China fifth metallurgical group Co., Ltd. official website)

4.2. The role of supply-chain spatial distribution in supporting industry–innovation integration

Tesla's midstream industry–innovation integration is supported not only by the vertical spatial integration of production and R&D in the Shanghai Gigafactory but also by the spatial distribution of its supply chain, reflecting the spatial logic of industry–innovation collaboration across the full industrial chain. According to the 2024 Tesla domestic supplier list published by Yuqian Consulting, there are 102 domestic suppliers providing products in areas such as electric motors, cabins, e-drive systems, charging facilities, chassis, vehicle bodies, and interior/exterior components.

Based on the location of suppliers' headquarters, they can be grouped into Shanghai, other cities within the Shanghai metropolitan area, and cities outside the metropolitan area, as shown in Table 3. Analysis of the types of products supplied shows a "siphoning effect" centered on Shanghai: nearby suppliers provide small parts, medium-distance suppliers deliver core components, and distant suppliers supply both but are mainly part-oriented. Downstream after-market services are more evenly distributed across distances.

Table 3. Tesla supplier distribution nationwide

Supplier Location	Number of Suppliers	Product Types Supplied
Shanghai	7	Interior/exterior components, charging stations, monitoring
Other Shanghai metropolitan area cities (Suzhou, Wuxi, Changzhou, Nantong, Yancheng, Taizhou, Hangzhou, Ningbo, Jiaxing, Huzhou, Shaoxing, Zhoushan, Xuancheng)	24	Central control screens, core e-drive components, interior/exterior components, PCBs, sensors, radar, inverters, charging stations
Outside Shanghai metropolitan area	71	Charging stations, interior/exterior components, battery materials, cabin systems, e-drive components, body castings, PCBs, other services

For suppliers outside the Shanghai metropolitan area, further regional breakdown is shown in Table 4. Tesla maintains close supplier relationships in the Yangtze River Delta, Pearl River Delta, and Beijing–Tianjin–Hebei regions. Besides widely distributed suppliers for battery materials and charging stations, the supply chain exhibits regional specialization: specific components and services are provided by suppliers in advantageous regions—for instance, mapping and communication service providers are concentrated in the Beijing–Tianjin–Hebei area, whereas integrated circuit and charging-network R&D partners are primarily in the Pearl River Delta. In addition to nationwide patterns, suppliers with exceptional product quality, even if outside major cooperation zones, are integrated as specialized product providers—for example, CATL in Ningde, Fujian supplies battery systems to Tesla. Overall, the supply chain displays regional specialized cooperation, point-based unique product supply, and extensive coverage of raw-material and market-service products.

Table 4. Distribution of Tesla suppliers outside the Shanghai metropolitan area

Supplier Location	Number of Suppliers	Products Supplied
Yangtze River Delta cities outside Shanghai metro (Nanjing, Yangzhou, Zhenjiang, Wenzhou, Jinhua, Taizhou, Hefei, Wuhu, Ma'anshan, Tongling, Anqing, Chuzhou, Chizhou)	9	Battery materials, central control screens, charging stations
Beijing–Tianjin–Hebei	8	Mapping services, communications operations, central control screens, motors, e-drive components, PCBs
Pearl River Delta	23	Battery materials, central control screens, e-drive components, charging network development, integrated circuits
Middle Yangtze River cities	4	Battery materials, charging stations, body castings, interior/exterior components
Central & Western China	3	Battery materials
Others	24	Battery materials, complete batteries, central control screens, high-voltage assemblies, cables, cooling materials

4.3. Policy support for the construction of industry–innovation integration platforms

The Lingang New Area, located in the southeastern corner of Shanghai's Pudong district, covers a planned area of 315 km² with a projected population of 650,000. The Tesla Gigafactory is situated within the advanced manufacturing zone of this area. In 2017, the automotive industry in Lingang New Area generated an output value of CNY 33.47 billion, accounting for 33.3% of the total regional output, while the new-energy equipment industry produced USD 18.76 billion, or 18.7% of the regional total.

Before Tesla’s entry, leading equipment-manufacturing enterprises such as SANY Heavy Industry had already settled in Lingang, establishing a preliminary industrial ecosystem [7].

As the selected location for the Tesla Gigafactory, Lingang New Area’s policy innovations and platform-building efforts provided a foundational framework for the factory’s construction and Tesla’s R&D activities. As shown in Figure 3, the New Area introduced a series of guiding and incentive policies across multiple dimensions, including project approval services, infrastructure development, public-service platform construction, technological innovation support, and application-expansion facilitation. These policies effectively accelerated the development of Tesla Shanghai, spanning site selection, construction, R&D, production, and testing stages.

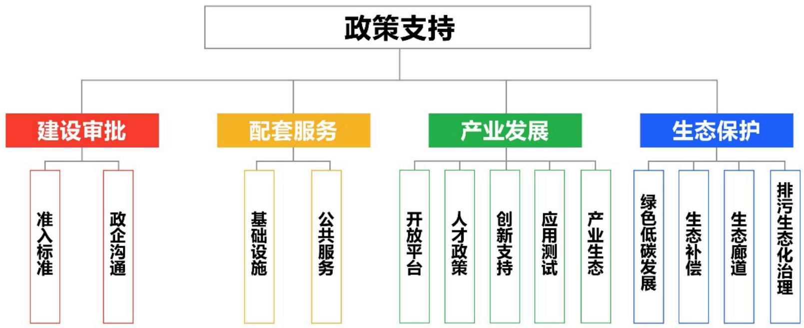

Figure 3. Policy support for the Lingang new area

During the establishment and operationalization of Tesla’s Shanghai plant, Lingang New Area focused on reforming project access standards as a core breakthrough, creating an efficient, coordinated approval-service system that ensured project implementation. It pioneered the “Three Alls, Three Poles, Three Max” approval framework, combined with land-use inventory systems, commitment-based approvals, and integrated “Two Evaluations, Two Certificates” processes, significantly streamlining project approvals. Additionally, the “Project Service Package” mechanism offered customized timelines and checklists for project milestones, enabling two-way government–enterprise communication and rapid problem resolution, improving approval efficiency while reducing costs and time burdens. In terms of land-use support, policies such as the “Implementation Plan for Regional Evaluation of Engineering Construction Projects in Lingang New Area (Trial)” optimized evaluation processes and provided standardized, efficient access for factory construction. Free infrastructure support for water, electricity, and gas further reduced the capital burden on enterprises. For regional industrial allocation, the “Four Ones” investment-attraction mechanism fostered high-end industrial aggregation, providing a robust industrial foundation for Tesla’s intelligent connected vehicle development.

At the level of supporting industry–innovation integration, Lingang New Area has developed a multi-dimensional policy system encompassing infrastructure, public services, talent policies, open platforms, testing scenarios, innovation-application management, and subsidies/incentives. Infrastructure and Open Platforms: The area enhanced regional logistics networks, established an international container-slot trading platform, and a one-stop digital integrated service platform, supporting enterprises’ international operations. Cross-border data platforms were also built to facilitate the circulation of industrial data elements. Public Services and Talent Support: The region established public-service clusters for high-precision map data and intelligent connected vehicle data collection/annotation, alongside comprehensive talent-service systems, ensuring technical and human capital support for industrial development. Testing and Innovation-Application Management: Professional testing platforms were established, and the New Area issued the nation’s first driverless ICV management regulations and operational guidelines, constructing a full-cycle national management system and digital supervision platform, providing standardized support for industrial testing and application. This comprehensive policy framework effectively underpins the industry–innovation integration of Tesla Shanghai, providing a strong policy-driven impetus for the growth of the intelligent connected vehicle industry.

5. Conclusion

5.1. Policy level

Shanghai’s Lingang New Area has effectively promoted the development of Tesla’s intelligent connected vehicle (ICV) industry through a variety of supportive policies, providing valuable lessons for other metropolitan regions aiming to develop ICV industry clusters. Construction Access: Policies on land and financial support reduced the cost of land acquisition for ICV enterprises, attracting companies to establish operations locally. An efficient approval mechanism was established, dividing the approval process into main and auxiliary streams running in parallel, and implementing mechanisms such as “supplement after acceptance” to compress approval timelines, optimize procedures, and accelerate project implementation.

Industry Cluster Development: Policies supporting industrial coordination and complementary development fostered a complete ICV industry chain, enhancing collaboration between upstream and downstream enterprises, improving industrial agglomeration effects, and strengthening competitiveness. Metropolitan areas are encouraged to enhance regional coordination, connecting testing scenarios and promoting shared development of ICV industries within the region. A data security regulatory system was also established, with government–enterprise collaboration to build secure data centers, ensuring that sensitive vehicle-generated data is encrypted and protected to maintain sovereignty and security.

Innovation and Talent: Talent-attraction and training policies were implemented, including facilitating entry, residency, and stay for foreign professionals, allowing patent-based eligibility for China’s green card, and providing relocation and housing subsidies. Collaborations with universities and research institutions cultivate local expertise. Enterprises are encouraged to enhance technological innovation and talent development, promoting industry-wide growth through technology sharing and mobility of talent.

5.2. Enterprise level

Tesla has established a unique industry–innovation integration model by constructing integrated R&D and production centers within the factory, where research centers, production workshops, and test facilities are co-located to enable efficient innovation, production testing, and mass manufacturing cycles. Independent R&D: By establishing its own research institutes, Tesla maintains independent core technological development capabilities, strengthening its R&D and innovation capacity. Patent Sharing: By openly sharing key technological patents, Tesla facilitates the transition of traditional internal-combustion vehicle manufacturers into the new-energy sector, lowering barriers to entry and expanding the ICV market. Charging Infrastructure and Standards: Tesla’s advanced, high-coverage charging network improves service quality, attracting other companies to adopt compatible standards, thereby expanding industry influence and improving competitiveness. Supply Chain Collaboration: Close partnerships with suppliers foster joint technological innovation and enhance product quality and production efficiency across the supply chain.

5.3. Spatial level

At the metropolitan area scale, suppliers covering the complete industrial chain of batteries, motors, and electronic control systems are developed within the local circle, while secondary suppliers are further attracted to locate nearby, cultivating a highly localized supply chain model. This not only reduces enterprise costs but also enhances industrial agglomeration, generating collaborative effects. High-speed supply chain responsiveness improves supply chain flexibility, and when combined with efficient supply chain management, it can effectively increase the production efficiency of intelligent connected vehicles.

At the park scale, the coordinated layout of production, R&D, and testing enables efficient transformation from innovation to product. Within the production area, the integrated arrangement of offices and production lines, together with the establishment of a supply chain management system, improves the operational efficiency of production lines. By increasing production automation levels and optimizing production processes, multiple production stages are arranged in a short-distance, integrated layout, thereby enhancing overall production efficiency.

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