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# Development of Deterministic Networking Techniques for Industrial Manufacturing

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**Abstract:** Deterministic networking for industrial manufacturing is a frontier technology offering both theoretical innovativeness and technical practicability; it is important for promoting technological innovation in the new-generation industrial Internet and for realizing the integrated development of industrial manufacturing and high-quality networks; as such, it offers an opportunity for expanding the frontiers of network technology and seizing new economic growth points. This study (1) investigates the development requirements for deterministic networking in industrial manufacturing, from the perspective of manufacturing and communication enterprises; (2) summarizes in detail the development status and trends of the technology; and (3) addresses further development challenges. We classify the technology's development into pilot demonstration, large-scale replication, and spontaneous innovation stages. Our research reveals that efforts to develop the "deterministic network + industrial manufacturing" model in China should focus on the following aspects: establishing industry alliances to improve the industrial ecology, maximizing the existing public networks, carefully selecting industry development paths, increasing the resource grants for application innovation, strengthening research regarding basic theories and key technologies, and training personnel through collaborations between industry, universities, and research institutes.
**Keywords:** industrial manufacturing; industrial Internet; deterministic network; time-sensitive network; fifth-generation (5G) mobile communication; quality of service

## 1 Introduction

The construction of an innovative country requires advanced networks, and the industrial Internet should be promoted alongside industrial manufacturing [1]. The development of industrial manufacturing depends on the upgrade of communication networks [2], and new-generation-network-technology-enabled industrial manufacturing has become an important development trend [3]. At present, Ethernet is widely used in industrial networks (e.g., factory intranet, factory extranet, etc.), and the amount of industrial equipment connected to the Internet protocol network has reached $1.2 \times 10^{10}$ units (as of 2020) [4].

The efficient usage, management, maintenance, and control of industrial equipment require network communication platforms and technologies that provide deterministic quality of service (QoS) as support. The

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upgrading of industrial manufacturing toward networking and intelligentization also demands a deterministic QoS in the network. Deterministic QoS includes the following: low latency (deterministic upper bound), low jitter (deterministic upper bound), low packet loss rate (deterministic upper bound), high reliability (deterministic lower bound), and high bandwidth (deterministic lower bound). The industrial manufacturing system is divided into multiple subsystems (e.g., real-time monitoring, machine vision, remote control, and material management), all of which require a deterministic QoS (Table 1). Typical deterministic networks include flexible Ethernet (FlexE), time-sensitive networking (TSN), deterministic networking (DetNet), and fifth-generation mobile communication (5G) deterministic networking (5GDN) [5,6]. Reference [3] analyzes the deployment of 5G and its commercial applications, concluding that 5G will considerably promote the development of the industrial Internet. Reference [5] summarizes the development status and trends of deterministic network technologies such as TSN, DetNet, and 5G, and it focuses on studying and evaluating the characteristics of related technologies in terms of ultra-low latency. Reference [6] elaborates upon the technical points and development trends of FlexE, TSN, DetNet, and 5G.

The existing research primarily discusses deterministic network technology and evaluates its development trends. This article focuses on the development analysis and a system demonstration of deterministic network technology for industrial manufacturing, and it proposes a three-stage development path, with a view to providing a technical reference for the applied research of deterministic networks in industrial manufacturing.

**Table 1.** Requirements for deterministic network QoS in part of the industrial manufacturing automation process [5].

| Scenarios | Latency (ms) | Jitter (μm) | Reliability (%) | Transmission rate (Mbps) |
|---|---|---|---|---|
| Remote control | 5 | – | 99.999 | 10 |
| Discrete automatic motion control | 1 | 1 | 99.999 9 | 1–10 |
| Discrete automation | 10 | 1000 | 99.99 | 10 |
| Process automation remote control | 50 | 20 000 | 99.999 9 | 1–100 |

## 2 Requirements of deterministic networking for industrial manufacturing

The development of deterministic network technology for industrial manufacturing will promote the development of networking and manufacturing techniques. The deep integration of deterministic network technology and industrial manufacturing will improve the entity industry and promote the enhancement of industrial manufacturing systems and management; at the same time, it will guide network service providers to provide high-quality and diversified service capabilities. Therefore, both industrial companies and network service providers require high-quality deterministic networks for industrial manufacturing [7].

### 2.1 Demands from industrial manufacturing upgrades

The current upgrade-based development trend of industrial manufacturing (Fig. 1) has driven the demand for deterministic networks. Since the 1980s, the global manufacturing layout has undergone fundamental changes. Following the technological development of communications, computers, mechanics, electronics, electrics, automation, and other fields, the global manufacturing industry has also shown new development trends.

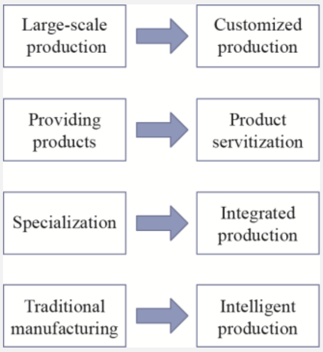


**Fig. 1.** Industrial manufacturing upgrading trend.

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To better fulfil the needs of the consumer market, industrial manufacturing has shifted from large-scale to customized production. The continuous improvement of people's living standards and the upgrading of consumer demand have promoted the development of niche, diversified, and customized manufacturing.

To further enhance the user experience, industrial manufacturing focuses have shifted from providing products to individualized and ecologically friendly services. Manufacturing companies no longer provide a single product but have become comprehensive service providers; as a result, the industrial field has been transformed from a single-product provision to an integrated product ecology and service.

To adapt to product customization and changes in the supply chain, industrial manufacturing has shifted from the specialized division of labor to integrated production. Enterprises' supply chains are showing new development trends. Manufacturing enterprises have tended to integrate upstream and downstream industrial information and develop into integrated production enterprises.

To improve production capacity and efficiency, industrial manufacturing has been transformed from traditional manufacturing to an intelligent digital production model. With the developments of emerging technologies (e.g., artificial intelligence, big data, Internet of things, Internet of vehicles, cloud computing, and robotics), new technologies and platforms have begun to be deployed inside and outside the factory. Correspondingly, the manufacturing companies' factory intranet, factory extranet, and data intercommunication modules all have specific and diversified requirements for deterministic networks [6].

### 2.2 Upgrade requirements of communication vendors

Communication manufacturers hope to improve technologies, expand the scope of services, and enhance service capabilities and value; thus, they have demanded deterministic networks [7].

Deterministic networking is the updating and iterative direction of communication manufacturers' technologies. Ethernet lacks real-time transmission quality assurance, global clock synchronization, bandwidth reservation, and data-packet filtering mechanisms; thus, it cannot guarantee deterministic QoS. Through technologies such as clock synchronization, frequency synchronization, traffic shaping, resource reservation, time-sensitive flow scheduling, and flexible slicing, deterministic networking services for industrial manufacturing at the level of converged Ethernet has become an important technology upgrade required by communication manufacturers.

Deterministic network is an important avenue by which communication manufacturers can expand their service range. With the channelized development of communication manufacturers, the upstream and downstream manufacturers of the communication industry chain hope to provide customers with differentiated, diversified, and personalized products and services, as well as to cultivate new business growth points. Industrial manufacturing enterprises have a high output value and large upgrade space, making them a service target that communication manufacturers are actively striving for. By providing high-quality deterministic network services, communication manufacturers can push into the front line of manufacturing and operations and expand the scope and diversity of services.

Deterministic networks represent an important tool for enhancing the service value of communication vendors. Deterministic networks can increase industrial data-transmission rates by a factor of several tens to hundreds compared to traditional Ethernet, and they can strictly control key indicators (e.g., end-to-end jitter and delay) to meet the needs of enterprises for real-time automation (e.g., robot control and unmanned vehicle scheduling). Technologies such as network slicing allow communication vendors to provide differentiated services, and high-quality, differentiated services also open up new revenue spaces for these communication vendors.

## 3 Development status and trend analysis of deterministic network technology for industrial manufacturing

### 3.1 Technology research status

Several of the current Ethernet expansion versions in the industrial field—including process field net (PROFINET), Ethernet control automation technology (EthernetCAT), time-triggered Ethernet (TTEthernet), hard real-time switch architecture (HaRTES)—can meet some of the needs of industrial manufacturing; however, because of the lack of bandwidth reservation, clock synchronization, packet priority filtering, and other mechanisms, these cannot fully meet the strict real-time and deterministic QoS requirements of the manufacturing process [6]. Deterministic network technology improves the Internet protocol network from "best effort" to "on time and accurate" in terms of providing end-to-end control of industrial platforms and equipment, and it has promoted TSN, 5GDN, and other deterministic network technologies as popular choices for industrial manufacturing upgrades.

To support deterministic communication in the industrial manufacturing process, the Institute of Electrical and Electronic Engineers (IEEE) has formulated the TSN technical standards, the Internet Engineering Task Force (IETF) has proposed the DetNet technical standards, and the Optical Internet Forum (OIF) has defined the FlexE technology [6]. 5GDN refers to the use of 5G resources to construct a predictable, plannable, verifiable, and deterministic mobile private network to provide differentiated business experiences [7,8], thereby creating a more flexible, efficient, and easy-to-deploy industrial deterministic network. At present, TSN and 5GDN have already begun commercial applications in industrial manufacturing, whereas DetNet and FlexE require further efforts to meet the needs of industrial manufacturing.

FlexE technology is primarily used in 5G bearer networks to provide support for the deterministic path of 5G network slicing; this can improve the customized and differentiated service capabilities of service providers. FlexE includes several sub-technologies, including the shim structure for network slicing, cross-transmission for end-to-end transmission, operation management and maintenance (OAM) to support end-to-end transmission monitoring, and channel protection to ensure reliability [6].

TSN ensures the deterministic service quality of the local area network. It can send periodic and aperiodic data streams within the same local area network. It includes a series of technical standards, including clock synchronization, stream reservation, and cyclic queuing, to ensure deterministic delay and jitter of physical and link layers [5].

5G is used to provide wireless access services; its main technologies and functions are as follows: enhanced mobile broadband, ultra-reliable low-latency communications, and massive machine-type communications. For example, ultra-reliable low-latency communication technology relies on 5G's low-latency, time synchronization, resource management, reliability, and other characteristics; with this technology, 5GDN ensures a deterministic low-latency and low-jitter network QoS.

DetNet is used to provide deterministic network services in wide area networks. Currently, only a few technical standards exist, including scalable deterministic transmission and cycle specified queuing and forwarding; these ensure a deterministic delay and jitter in the network layer [5]. Other relevant technical standards are still being formulated.

The applications of deterministic networks in manufacturing companies can be subdivided into machine vision, real-time monitoring, remote control, material management, auxiliary operations, massive connections, life-cycle management, and more (Fig. 2). Operations are already underway in large manufacturing companies [7].

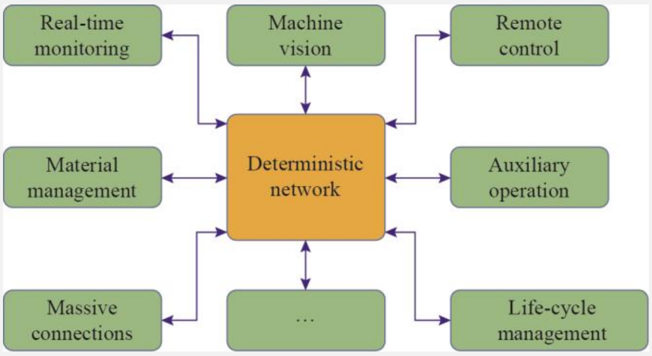


**Fig. 2.** Applications of deterministic network technology in industrial manufacturing.

Alongside enterprise applications, research into deterministic experimental platforms has been conducted; one representative example is the future network experimental facility CENI. CENI can provide a large-scale open test

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environment for the deployment, testing, and verification of future network architectures and key technologies. CENI has performed successful ultra-long-distance deterministic low-latency and low-jitter data transmission experiments, completed ultra-long-distance (2000 km) motor synchronization control experiments, and verified the feasibility of an ultra-long-distance real-time industrial manufacturing control based on deterministic networks [9].

### 3.2 Technology development trend

TSN provides deterministic transmission services for high-priority traffic, by using time-division multiplexing scheduling technology at the link layer to ensure low latency and jitter; however, this can increase the delay of low-priority traffic. Statistical multiplexing can be applied to provide delay boundary guarantees for such traffic [6]. The centralized or distributed deployment of TSN and technologies for connecting multiple closed time-sensitive networks are subjects that require further research. New standards definitions, technical implementations, and experimental testing are current research hotspots in terms of the combined TSN and 5G.

Compared with TSN’s, DetNet’s flow control operation faces challenges such as larger scales, longer transmission distances, and higher scheduling complexities. Both TSN and 5G are commercially available, though DetNet’s technical standards are still in the formulation stage. Therefore, wide-area deterministic network services require further research in areas such as data-flow control, forwarding, and QoS guarantee technologies.

Using FlexE’s network slicing technology, operators can segment multiple virtual networks (with a guaranteed service quality) and physically isolated services within one hardware infrastructure; the corresponding OAM functions can satisfy the demands of network maintenance [6]. With the help of FlexE technology, providing flexible bandwidth and customized service quality, improving network utilization, and realizing a diversified service system for different industrial manufacturing processes have become important development trends.

5G has been commercialized, and its integration with the local area network TSN and wide area network DetNet will further enhance the service capabilities and quality of industrial manufacturing. The combination of 5G and FlexE provides differentiated service capabilities for 5GDN. Reducing the cost of network construction and broadening the scale of applications in industrial manufacturing has generated new research requirements regarding the design of the 5G tariff system.

Furthermore, the important development trends of deterministic network technology are as follows [6]: properly handling the relationship between network architecture innovation and gradual deployment, designing security protection mechanisms (e.g., fault handling and fault tolerance mechanisms), and promoting the integration of various technology layers. The construction and launch of the large-scale “deterministic network + industrial manufacturing” experimental platform represents another important development trend. The integration of the manufacturing process of CENI and industrial manufacturing enterprises can also be further expanded.

## 4 Challenges in the development of deterministic network technology for industrial manufacturing

### 4.1 Shortcomings in the informatization and digitalization of manufacturing enterprises

One prerequisite for the full deployment of deterministic networks in the industrial manufacturing field is that the digitalization and informatization level of manufacturing enterprises or factories must reach a certain level. However, numerous manufacturing enterprises in China (including large enterprises) still suffer from clear shortcomings. The statistical data for the 150 000 industrial enterprises participating in the Industrialization and Industrialization Convergence Service Alliance’s evaluation [7] show that, as of the second quarter of 2019, the digitalization rate of production equipment and the numerical control rate of key processes were 47% and 49.2%, respectively, and the smart manufacturing ready rate was only 7.6%. Most of the participating enterprises were large. The Industrial Internet Industry Alliance’s survey data for China’s industrial enterprises [7] show that enterprises face outstanding problems such as small data stocks and outdated management methods. For example, 66% of enterprises store less than 20 TB of data (less than 1/10 of the daily increase in data volume for a provincial telecom operator), and 51% of enterprises still use relatively rudimentary methods (e.g., documents) for data management.

Once the informatization and digitization of industrial enterprises have attained a certain level, the “deterministic network + industrial manufacturing” model can be successfully implemented. In the absence of solid digital and information conditions, even if deterministic-network-based industrial manufacturing applications can be achieved, it will ultimately be difficult to form the expected pattern of large-scale applications and value creation. Whilst ensuring that the degree of informatization and digitization can satisfy the construction and development needs of manufacturing enterprises, efforts should be made to realize the deployment of deterministic networks in industrial enterprises and their synchronization with other informatization and digitization facilities.

### 4.2 Barriers to the integration of deterministic networks and industrial manufacturing

The integration of deterministic networks and industrial manufacturing remains in its infancy, and its applications must be further explored; in contrast to the consumer Internet, the industrial Internet presents difficult obstacles to the integration and development of technology, architecture, and business models between communication-operation and industrial manufacturing companies. Operators and equipment vendors have an insufficient grasp of the technology, characteristics, and business and technological processes of the industrial manufacturing industry, and a certain degree of cross-border disparity is visible: network operators lack large-scale, high-quality deterministic network services for high-end manufacturing, and it is difficult to comprehensively and accurately support the actual production and operation needs of industrial manufacturing enterprises. In addition, the deterministic network deployment scale of global operators is not yet able to support the deterministic network service needs of large range and wide coverage. Operators tend to choose typical industries and scenarios, combine them at their own deterministic network construction pace, and implement gradual deployment in a piloted manner. For example, the regional deployment of deterministic networks combined with mobile edge computing can be deployed as priority pilots in industrial parks and other highly independent industrial manufacturing areas.

During the integrated development of deterministic networks and industrial manufacturing, the cross-border cooperation and supply–demand connection between deterministic networks and industrial manufacturing enterprises must be strengthened. Deterministic network commercial application pilot demonstrations can be conducted in key areas using intensive industrial manufacturing, and open, profitable, and sustainable new business models can be actively explored.

### 4.3 Insufficient maturity of deterministic network technology

The existing application results show that deterministic networks are still limited by their technological maturity; this restricts their facilitating role in industrial manufacturing. For example, for 5GDN, the technical maturity issues are analyzed as follows [7]. (1) In terms of reliability, because of the interference and fading generated by the sudden environmental changes unique to wireless networks, the reliability of 5G cannot be consistently maintained above the 99.9999% threshold; industrial production is highly sensitive to delay and reliability. It is necessary to flexibly and autonomously control the frame structure and coding strategy through wireless network slicing, to improve stability; furthermore, strategies such as application-oriented customization of the wireless-network-underlying coding method can also be considered. (2) In terms of network communication capacity and efficiency, the technology remains in the pilot stage. As the “industrial bus” of the future factory, 5G must meet the needs of machine vision, real-time monitoring, and other applications featuring a large number of data uplinks, and different devices and applications require diverse access routes. (3) In terms of terminal support, factors such as the technological maturity and cost of 5G industrial modules directly affect the application of 5GDN in industrial manufacturing enterprises. It is expected that as the number of related manufacturers increases, product maturity will increase and costs will decrease.

Although numerous deterministic network standards and technical specifications have been published, test scenarios for large-scale industrial manufacturing are still lacking, and further applications are needed to enhance the confidence of the industry and consumer markets [5]. Attention should be paid to improving evaluations of closed-loop stability for various scenarios in “deterministic network + industrial manufacturing,” to form multi-scenario, multi-dimensional, and reusable success cases.

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### 4.4 Deterministic network service cost and talent cultivation

Commercial deterministic networks (e.g., 5GDN) currently exist; however, several enterprises (especially small and medium-sized enterprises) still have concerns about the future tariffs of deterministic networks; expressed otherwise, excessively high deterministic networking tariffs may increase the production costs of enterprises. The solution to these problems requires deterministic network operators to comprehensively improve their service capabilities and technological maturity; manufacturers to significantly reduce equipment production, manufacturing, and maintenance costs; and government authorities to moderately participate in the initial market pricing argumentation.

"Deterministic network + industrial manufacturing" is a typical cross-industry application, and mature talents are in short supply. Potential personnel are distributed across universities, scientific research institutions, and enterprises, studying majors in communications, computers, automation, mechanics, electronics, electrics, and more. The lack of professionals restricts industry development. Universities and enterprises should actively connect around the relevant training strategies. Universities or research institutions can form new majors or departments, deepen industry–university–research cooperation, strengthen the training and deployment of talents for the "deterministic network + industrial manufacturing" industry, and form a combined practical, professional, and technical personnel team as soon as possible.

## 5 Development stage division of deterministic network technology for industrial manufacturing

Deterministic networks for industrial manufacturing aim at (1) constructing a large-scale information infrastructure that can provide deterministic service quality, thereby providing real-time, high-quality, and highly reliable network services for industrial manufacturing upgrades; and (2) fully promoting industrial manufacturing. The construction of a deterministic network development system for industrial manufacturing is a gradual process. Based on the demonstration of technical and commercial feasibility, the integrated development of "deterministic network + industrial manufacturing" can be divided into three stages.

### 5.1 Pilot demonstration stage

In this stage, suppliers (e.g., operators, equipment manufacturers, and solution providers) actively cooperate with the demands of various industrial manufacturing enterprises, to conduct demonstrations and pilot projects for key industrial manufacturing scenarios. Industrial manufacturing companies place clear requirements for deterministic network performance in their own business scenarios, and the supplier guarantees these deterministic requirements by integrating various technical provisions. Through successful piloting of the deterministic network in industrial manufacturing scenarios, the "deterministic network + industrial manufacturing" model is transformed from technical demonstrations to practical applications, which highlights value creation and has a demonstrative effect.

In terms of technical feasibility, TSN and independent networking 5G are the most mainstream deterministic network service technologies currently capable of satisfying the deterministic requirements of low latency, high reliability, high bandwidth, and massive connections; technologies such as network slicing are gradually becoming mature and better able to support deterministic network customized services. Compared with their non-independent counterparts, independent networking architectures form the basis for technologies such as network slicing, super uplink, and edge computing. Technical features such as two-way low latency and large uplink bandwidths can effectively support the needs of industrial manufacturing services.

In terms of commercial feasibility, because industrial manufacturing companies are cautious about the application of new information and communication technologies, pilot demonstration projects should be started with a low and then steadily increasing level of investment. During the initial stage of deterministic network commercialization, the direct benefits of applications in various vertical fields may not be obvious, and most industrial manufacturing companies adopt a wait-and-see attitude. Hence, those industrial manufacturing scenarios with considerable potential for improving manufacturing efficiency and convenient transformation can be selected, and pilot applications can be implemented first.

### 5.2 Large-scale replication stage

In this stage, both the supply and demand sides actively explore the large-scale implementation of the "deterministic network + industrial manufacturing" model, and the effect of the deterministic network upon industrial manufacturing is made apparent. At this stage, the manufacturing efficiency of industrial manufacturing enterprises has been significantly improved, the information integration of the upstream and downstream industrial chains is good, and the basic feasibility conditions for large-scale applications in the industrial manufacturing field are available.

In terms of technical feasibility, the deterministic network enters large-scale commercial use, and the access and core network functions tend to be improved. The deterministic network functions supporting various scenarios can be directly applied to meet the needs of various manufacturing enterprises' scale application requirements. The deterministic network system is essentially completed, forming an industrial Internet service architecture with FlexE as the bearer network and TSN and 5G as the access one. The service quality can be varied according to the intelligent manufacturing scenario, and all-weather, multi-scenario, multi-dimensional manufacturing enterprise service capabilities are made available in enterprise zones whilst ensuring the security of enterprise private data and the stability of deterministic network service quality.

In terms of commercial feasibility, according to the first phase of the pilot demonstration, the supplier and demander perform multi-scenario and multi-stage application runs to form a complete cooperation model, including industry standards, plan implementation, and business models. The customized network slicing service model is matured, and manufacturing companies can flexibly switch network service qualities according to the actual needs of different manufacturing scenarios, taking into account the improvement of production efficiency and production cost control; when the industrial module technology is mature, the cost is lowered, the marginal cost of large-scale replication is steadily reduced, and the technology can be actively used by most industrial manufacturing companies for upgrading production processes, improving product yields, and providing customized industrial products.

### 5.3 Spontaneous innovation-driven stage

After a long period of commercial use, all aspects of the deterministic network have matured and become part of the core infrastructure driving the digital transformation of the manufacturing industry. The development of the industrial manufacturing industry has also entered a new stage, and the industry is highly motivated by innovation. The various standards, technical solutions, and business models applied by deterministic networks in many industrial manufacturing scenarios are relatively mature, and the "deterministic networks + industrial manufacturing" model has fully entered the stage of spontaneous innovation. At this stage, the deterministic network may become the standard configuration of the industrial scenarios. One typical feature of this stage is that the demand-side groups of various industrial manufacturing enterprises become the main driving force and spontaneously innovate within each segment of the industrial Internet. These groups generate demand during the innovation process and expand the applicability of deterministic networks across a wider range of industrial scenarios.

In terms of technical feasibility, the deterministic network system tends to be perfected, forming an architecture with DetNet as the core network, FlexE as the bearer network, and TSN and 5G as the access network. The local area, wide area, wired, and wireless deterministic networks are deeply and organically integrated, and the scope of services is extended to large-scale and ultra-large-scale industrial manufacturing zones; this supports the direct application of deterministic network functions in various scenarios, and it provides interfaces for industrial manufacturing companies to allow manufacturing companies to participate in customization; furthermore, each segment of the deterministic network can better meet the differentiated needs of enterprises.

In terms of commercial feasibility, by this stage, the cost for most industrial manufacturing companies has been further controlled, the product yield rate has been greatly improved, and higher product additional values can be obtained; these deterministic networks can respond quickly to the needs of users for customized products and comprehensive design and production procedures. The willingness, capacity, and approaches for active participation in the improvement of sub-fields of the deterministic network are strengthened, and further

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diversified business growth points can be sought.

## 6 Strategies and suggestions

### 6.1 Establishing industrial alliances to promote ecological development

In deterministic networks for industrial manufacturing, the in-depth development and ecological prosperity of the network depend on multiple links in the upstream and downstream directions of the industrial chain and are also inseparable from the joint efforts of management departments, enterprises, institutions, and social groups. It is preferable to take the form of an industrial alliance, to gather consensus and strength from all parties, eliminate information asymmetry, and promote the implementation of product applications.

All industrial alliances should strengthen their cooperation and coordinated development, build an integrated information platform within the industry, and implement a series of innovative development demonstration cases. Related development priorities are as follows: (1) Resource sharing: the primary task of the industry alliance is to eliminate information asymmetry and resource unevenness and build an integrated resource sharing platform. The sensitive resources of the alliance members can be managed by authorized use. (2) Joint research and development: shared resources further promote the integration of the R&D processes of the upstream and downstream parties in the industry chain, to improve R&D capabilities and efficiency. (3) Project implementation: the most important task of the industry alliance is to promote the implementation of “deterministic network + industrial manufacturing” application projects, to help industrial manufacturing enterprises obtain high added value and simultaneously improve the service capabilities of communication service providers. (4) Integrated development: the industry alliance will eventually promote a high degree of integration between the upstream and downstream directions of the industrial chain, bringing mutual benefits; at the same time, it also respects the differences and diversity of members.

### 6.2 Accelerating the formation of a first-mover advantage to the public network privatization

China’s network infrastructure is rapidly developing, particularly in the field of mobile networks. It is preferable to accelerate the development of the first-mover advantage of the public network, realize deterministic network services for industrial manufacturing enterprises on the 5G public network, and accelerate the formation of more demonstrative applications of “deterministic network + industrial manufacturing.” For example, this can be achieved by building an industrial-grade TSN based on 5G and applying it to smart manufacturing scenarios, or building a dedicated network for enterprises and research institutions to test and verify remote industrial manufacturing technologies based on the CENI public network.

In terms of providing deterministic network services exclusively on the public network, it is preferable to pay attention to the following aspects: (1) Customized services: the deterministic network services provisions must take into account the actual needs of industrial manufacturing enterprises and provide customized private network services across multiple stages, dimensions, and scenarios. (2) Demonstration projects: forming typical successful cases specific to the public network and providing reference models for several industrial manufacturing enterprises to upgrade. (3) Implementation of applications: public networks dedicated to realizing practical applications and generating industrial value as the fundamental goal. (4) Comprehensive integration: realizing public network specialization in a way that is not limited to a single deterministic network technology, and comprehensively integrating multiple technologies (e.g., network slicing and edge computing, etc.) to upgrade the industrial manufacturing system.

### 6.3 Paying attention to the selection of industry development paths

The “deterministic network + industrial manufacturing” model is still in the initial stages of development, and it is advisable to implement a gradual promotion strategy to lay a solid foundation for large-scale integrated development. The industry development path must be optimized, and it is preferable to focus on the following areas: (1) Industry suitability: industrial manufacturing involves many sub-sectors, and those sub-sectors that require high deterministic service quality (e.g., production process automation) should be deployed first. (2) Appropriate scenarios: selecting scenarios that are relatively mature in terms of technology and standards and are closely related to the operator's ability to connect to pipelines (e.g., machine vision scenarios) in industrial manufacturing. (3) Regional suitability: because of the insufficient basic network coverage for providing deterministic network services, the deterministic network can be deployed independently in combination with mobile edge computing. Electrical equipment industrial manufacturing parks, ship manufacturing bases, and other regions with strong independence should be deployed first.

### 6.4 Increasing resource grants for application innovation and development

It is recommended to accelerate business model innovation, improve operator tariff systems, introduce industrial standards, combine industry practices, and explore new industrial ecology models. It is necessary to give full play to the leveraging effect of public funds, and guide social capital to increase investment in the "deterministic network + industrial manufacturing" industry. It is also important to encourage all types of bank credit and investment funds toward the "deterministic network + industrial manufacturing" direction, support industrial manufacturing enterprises in their "deterministic network + industrial manufacturing" product development, improve the production efficiency and product quality of manufacturing enterprises, and reduce manufacturing costs.

### 6.5 Strengthen research regarding basic theories and key technology

Basic theoretical research and key technological breakthroughs are important foundations for the development of "deterministic network + industrial manufacturing." It is recommended to strengthen the research on the following theories and technical directions: intelligent manufacturing principles, automatic control principles, network design principles, deterministic transmission principles, artificial intelligence principles, large-scale forwarding mechanisms, deterministic scheduling mechanisms, flexible slicing technologies, deterministic transmission equipment, device manufacturing, and more. At the national level of science and technology investment, it is recommended to reasonably increase support for "deterministic network + industrial manufacturing" related research, add necessary specific research topics, promote the development of cross-industry technology and the application integration of scientific and technological achievements, and design the required scientific and technological support systems to satisfy the urgent needs of industry development.

### 6.6 Focusing on the cultivation of integrated talents with industry–university–research cooperation

It is recommended that the competent departments take the lead and unite universities, scientific research institutions, enterprises, and public institutions, to demonstrate and construct an integrated talent cultivation mechanism and industry–university–research cooperation reflecting the needs of the industry. Furthermore, it is advised to optimize the allocation of educational resources, accurately cultivate compound talents, and provide intellectual support for the solid development of "deterministic network + industrial manufacturing." In view of the current state of "deterministic network + industrial manufacturing," which suffers from a shortage of mature talents and scattered potential talents, it is recommended to establish a "deterministic network + industrial manufacturing" interdisciplinary research center, to simultaneously perform talent training and research and consider the smooth transformation of research results.

## References

[1] State Council of the People's Republic of China. State Council guidance on deepening the development of industrial Internet in the "Internet + advanced manufacturing industry" [R]. [EB/ OL]. (2017-11-27) [2020-12-15]. http://www.gov.cn/zhengce/content/2017-11/27/content_5242582.htm. Chinese.

[2] The Research Group for *Research on Intelligent Manufacturing Development Strategy*. Research on intelligent manufacturing development strategy in China [J]. Strategic Study of CAE, 2018, 20(4): 1–8. Chinese.

[3] Zhang Y Y. 5G will fully enable the industrial Internet [J]. Telecommunications Science, 2019, 35(1): 7–14. Chinese.

[4] Cisco Systems. Cisco visual networking index: Global mobile data traffic forecast update, 2015—2020 [EB/OL]. (2016-02-03)[2020-12-15]. https://www.cisco.com/c/dam/m/en_in/innovation/enterprise/assets/mobile-white-paper-c11-520862.pdf.

DOI 10.15302/J-SSCAE-2021.02.004

[5] Nasrallah A, Thyagaturu A S, Alharbi Z, et al. Ultra-low latency (ULL) networks: The IEEE TSN and IETF DetNet standards and related 5G ULL research [J]. IEEE Communications Surveys Tutorials, 2019, 21(1): 88–145.
[6] Huang T, Wang S, Huang Y D, et al. Survey of the deterministic network [J]. Journal on Communications, 2019, 40(6): 160–176. Chinese.
[7] 5G Deterministic Networking Alliance. White paper on 5G deterministic network + industrial Internet [R]. Beijing: 5G Deterministic Network Alliance, 2020. Chinese.
[8] 5G Deterministic Networking Alliance. White paper on industry of 5G deterministic network [R]. Beijing: 5G Deterministic Network Alliance, 2020. Chinese.
[9] Qiang L, Liu B Y, Yu D L, et al. Large-scale deterministic network forwarding technology [J]. Telecommunications Science, 2019, 35(9): 12–19. Chinese.