

Development Status and Trend of Standards Digitization

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Abstract: Standards digitization is the inevitable result of economic and social development, digital technology change, and international strategic games. It is key to realizing the digital transformation of the national quality infrastructure (NQI) and has strategic significance for the Digital China initiative. This study reviews the demands of standards digitization and the research and practices of standardization organizations and key countries. The future development trends of standards digitization are analyzed in depth from the aspects of performance form, development mode, and social influence. Furthermore, it puts forward several suggestions for the digitization of standards in China, considering these trends. Specifically, a standards digital transformation organization should be established to improve the working mechanism, and generic and key technologies need to be developed to lay a science and technology foundation for standards digitization. The pilot scope should be expanded to cultivate an industrial ecology, and international cooperation and exchanges should be encouraged to integrate China into the global wave of standards digitization.

Keywords: digital transformation; National Quality Infrastructure (NQI); standardization; standards digitization; open-source

1 Introduction

With the continuous advancement of the industrial digitization process, digital technology has been applied on a large scale, and industrial efficiency has improved. In 2019, the digital economy scale of 47 major economies in the world reached \$31.8 trillion USD, accounting for 41.5% of the increase in gross domestic product (GDP). The added value of China's digital economy also accounted for 36.2% of the GDP, and the nominal growth rate was 7.85% higher than that of GDP during the same period [1]. Faced with such rapid economic and social development, it has become a common concern in the field of standardization worldwide to meet the needs of industrial development for standard-setting efficiency and use modes in the context of digital transformation.

The research and development of standards digitization began with the interaction between open-sources and standardization. On one hand, it actively introduces standardization principles and methods in the open-source field. The Danish Parliament first proposed three kinds of requirements for "open standards" in 2006, which was the beginning for standards organizations to introduce open-source technology into the field of standardization [2]. Subsequently, the cooperation between the open-source community and standardizing organizations became closer, and open-source standards organizations such as the Open Container Initiative (OCI) emerged, which simultaneously promoted standard-setting when carrying out open-source projects, and introduced open-source technology into the standard-setting process [3]. Since 2015, OCI has successively launched open-source standards

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such as Runtime-spec and other corresponding standardized document development procedures [4]. On the other hand, standardizing organizations were also actively cooperating with the open-source community to jointly complete the formulation, implementation, and promotion of standards [5]. In 2017, the European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC) issued the *CEN-CENELEC Digital Transformation Strategic Plan*, which was expected to ensure that the standardization needs of digital transformation in the industrial field are met by standards digitization, so that CEN and CENELEC's standardization systems could be more agile and meet the needs of market and technological innovation [6]. Affected by this, the International Organization for Standardization (ISO) also put forward the concept of "Standards Machine Applicable, Readable and Transferable (SMART)" in 2019 to drive standards digitization in the direction of machine-readable standards [7]. Research in the technical field focuses on standards data mining, knowledge management, and intelligent applications [8].

Presently, the technical paths and stages of the standards digitization research of various entities are different, however, they affect the pattern of digital ecology in the future. 2021 was the first year of China's 14th Five-Year Plan. It is necessary to systematically summarize and prospect the current status, problems, and future trends of standards digitization; to effectively grasp the opportunity of world digitization and improve China's standards digitization level and international competitiveness.

2 Requirements for standards digitization

Standards digitization refers to the process of enabling the standard itself and ensuring its entire lifecycle using digital technologies (cloud computing, big data, blockchain, Internet of Things, artificial intelligence, etc.), so that the rules and characteristics carried by the standard can be read, transmitted, and used through digital devices. Its emergence and development are not only the objective needs of economic and social development, but also the response of standardization itself to the change in digital technology, and it is also the focus of international strategic games.

2.1 Standards digitization is the objective need for China's economic and social development.

Digital technology has had a profound impact on China's industrial development, daily life, government management, and services. Chinese leaders and relevant departments fully recognize the role of digitization in the development of the national economy. In 2018, Secretary-General Xi Jinping proposed in his speech at the 19th Academician Conference of the Chinese Academy of Sciences and 14th Academician Conference of the Chinese Academy of Engineering, that it is necessary to seize the opportunity for the integrated development of digitization, networking, and intellectualization, and promote the in-depth integration of the Internet, big data, artificial intelligence, and the real economy [9]. In March 2021, the *Outline of the 14th Five-Year Plan (2021-2025) for the National Economic and Social Development and the Long-Range Objectives Through the Year 2035*, proposed accelerating digital development and building digital China as an independent chapter, in which standards digitization is the standardization basis for the construction of the digital economy, digital society, and digital government [10]. The *Outline of National Standardization Development* issued in October 2021 clearly demands the development of machine-readable standards and open-source standards to promote the transformation of standardization work to digitization, networking, and intellectualization [11]. It should also be noted that the current standards digitization level in China does not match economic and social development. For example, the renewal cycle of the mobile phone industry is typically half a year, and the relevant key technologies will be updated every few months, while the traditional standard-setting cycle in China is an average of 30 months [12]. Therefore, the construction of standards digitization could upgrade the digitization level and capacity of the national quality infrastructure (NQI), which is the basic demand for realizing the Digital China strategy.

2.2 Standards digitization is the need of standardization for dealing with changes in digital technology.

Standards digitization is not only the product of technological development, but also the basic demand of the digital age and the inevitable stage in the modernization process of standard-setting and use. With the continuous development of digital methods and technologies such as open-source and blockchain, a variety of related concepts, forms, and setting methods have emerged, such as open-source standards [13], open standards [2], SMART standards [7,14], digital standards [15,16], and BSI flex [17,18]; thus, the characteristics and development

requirements of all walks of life can be satisfied. Carrying out standards digitization research in a timely manner can improve relevant concepts, principles, methods, common technologies, and field applications from a basic perspective, and propose a standards digitization technology route suitable for national conditions.

2.3 Standards digitization is the commanding height of inter-nation standards competitions.

ISO, IEC, CEN, CENELEC, and other international and regional standardizing organizations, as well as developed countries such as the United Kingdom, the United States, and Germany, have incorporated the realization of digital transformation of standards into their standardization strategy; and have taken the lead in research and applications in related fields, construction, and social governance [19–27]. At the international level, the *IEC Development Plan (2017)* mentions that IEC will continue to prepare for fundamental changes that will affect its core operations, such as open-source and open data trends, and new digital standards used directly through machines [20]. At the regional level, the *CEN-CENELEC Strategy (2030)*, released in 2020, aims to provide customers with digital solutions, and requires adjustments according to their changing needs and expectations, so as to provide market-related digital standards in time [22]. At the national level, the *German Standardization Strategy* issued in 2016 requires the integration of digital technology into the standardization setting-process and makes full use of digital resources in the work of the committee [26]. In 2018, *A National Machine Intelligence Strategy for the United States* released by the U.S. Center for Strategic and International Studies believed that the U.S. government could coordinate its own data structure and label standards, cooperate with enterprises to set standards, and realize data sharing between the government and industry, so as to promote standards digitization [28].

3 Development status of standards digitization

3.1 International development status

3.1.1 ISO SMART Standards

Currently, ISO publications are open to the public and are committed to human beings as the standards users. However, stakeholders in relevant industries and fields are exploring new delivery mechanisms to quickly develop and apply standards. In 2019, the ISO proposed a new standard concept called SMART standards, which redefined the standards in a digital background. Machine-readable standards are the products of the current stage of standards digital development, which were presented in a new format. Machines can directly read and execute (i.e., automatically work in the system) and have a shorter setting cycle, such as database standards and standards containing code components. The ISO has established a machine-readable standards ad hoc group and a machine-readable standards strategic advisory group (SAG MRS). SAG MRS is mainly responsible for preliminary research work on standards digitization, such as formulating the technical roadmap of SMART standards, introducing and implementing SMART standards (including the understanding and interpretation of these standards, considering the relevant initiatives of existing countries and regions), planning in detail the priority of ISO standards from text-based to digitized, and developing guidelines for relevant ISO technical committees on the implementation and interpretation of standards digitization [7]. At this stage, ISO defines the development stage and characteristics of SMART standards based on the work results of the group. According to the interaction degree between the content and the machine, the evolution of the standard is divided into five stages: paper, open digital format, machine-readable document, machine-readable content, and machine interpretable content (Fig. 1). The use of digital technology is gradually deepened in each stage, such as text recognition, extensible markup language (XML), ontology modeling, and knowledge graph. ISO defines its own standards digitization level in the machine-readable document stage; that is, it uses XML to implement the structuring of document content so that standards content can be quickly identified and retrieved. This is also the focus of current standards digitization research. Although CEN, CENELEC, and German Institute for Standardization are also present in the third stage, based on their own industrial practice, they have begun to explore and develop standardized software matched with standard text, which is used to carry the rules and characteristics defined in the standards, and can be directly executed by the machine [29].

			Machine capabilities	Machine limitations
Level 1	Paper			• No machine interaction was possible
Level 2	Open digital format	• Read and search on screen 	• Basic search • Online preview	• Very little machine-interaction was possible
Level 3	Machine-readable document	• Structured content of the standard documents • Content can be processed by software 	• Simple tagging • Simple search • Well-structured document • Document can be easily parsed by software	• No understanding of the search results or parsed content
Level 4	Machine-readable content	• Semantic enrichment of the content for selective access • Receives content for multiple standards for a given purpose 	• Semantic description of tagging • Advanced search on meaningful and defined elements • Basic capabilities to find and process elements like graphs, formulas, and executable code	• Ontology was lacking to place elements in context
Level 5	Machine-interpretable content	• Information modeling that expresses the content and relationship between elements • Self-learning analysis and validation cycles to improve content handling and access • Interruption-free data flow within the value chain • Automatic question answering or predictive content supply 	• Ontology exists for the relationship between addressable elements • Automatic generation of standardized files • Machine can find and use elements in a given context and perform operations on it	

Fig. 1. ISO definition of the standard development stages and characteristics [8]

3.1.2 European regional standardizing organization

CEN and CENELEC conducted research on standards digitization earlier than ISO. In 2018, they launched three projects, “online standardization,” “future standards,” and “open-source innovation,” all of which are directly related to standards digitization. The “online standardization” project aims to support the modernization and digital transformation of standard-setting in CEN and CENELEC, mainly focusing on the online collaborative writing platform, so as to provide a high-end customized writing environment for CEN and CENELEC technical institutions with ISO/IEC. The technical evaluation and pilot preparation were completed in 2019 and officially launched in 2020. The “future standards” project aims to support CEN and CENELEC to reconstruct the content using XML to facilitate machine-readable and translatable standards, and the pilot work of the “future standards” application was launched in the fields of architecture and petroleum. The “open-source innovation” project aims to fully tap the application potential of open-source technology in the field of standardization and provide potential innovative technical support for standards digitization [30].

In 2019, CEN and CENELEC carried out legal analysis around the intellectual property rights protection of digital standards content, aiming to solve the legal problems caused by the transformation of standard text to machine-readable/translatable content, and intellectual property problems related to open-source and online standard writing platforms.

3.1.3 Relevant work in major countries

The British Standards Institution (BSI) conducted a survey on the applicability and future trends of the current standards in 2019. It proposed that the nature of the standards needs to be changed to improve their practicability, and that the development cycle of deliverables is also very important. Therefore, BSI has launched an agile process for the collaborative development of standards in a digital environment, which can form deliverables in a few weeks and is expected to significantly shorten the standard-setting cycle [24]. Based on this research, BSI formally proposed the BSI Flex standards in 2020 as a supplement to BS and PAS standards, thereby meeting the rapidly changing market needs [17]. The BSI Flex is a rule-based online standard-setting method that can share practical experiences. Each new version of the standards was publicly consulted and reviewed to ensure that it could be used by all types of users. The standards developed using this method are referred to as the BSI Flex standards. This method adopts open-source community platforms, such as GitHub and Stack Overflow, to support rapid iteration of development, sharing, and implementation. It is characterized by flexible development, rapid iteration, evolutionary response, and open negotiation. It is suitable for emerging and rapidly evolving fields [18]. At present, the BSI has launched two BSI Flex standards and conducted a public inquiry [31,32], which are used to meet the standards requirements of COVID-19 prevention and the Internet of Vehicles.

The American National Standards Institute (ANSI) believes that standards digitization has three main directions: creating new tools and methods to develop standards, allowing more people to participate in standardization work, and forming new types of standard deliverables. This allows the exploration of different publishing formats, such as using more flexible and stable XML technology; and the direct integration of standards into products, systems and services [33]. In 2019, ANSI and other American industry partners began to implement ISO SMART standards, which is typically undertaken by the ISO/IEC Joint Technical Committee 1 (JTC 1) [14], by integrating the contents of ISO standards into products, processes, and services to significantly save on time and cost. In 2019, the National Artificial Intelligence R&D Strategic Plan of the United States began to promote the use of standardized or open-format resources and open standards for representing semantic information, gradually establishing and improving the digital ontology of standards in related fields [27]. In 2020, ANSI listed the ISO SMART standards as one of the six emerging cutting-edge technologies that collaborate on technical solutions in its annual report, believing that the SMART standards are of strategic importance, and that the world is developing towards digitization, and the development and use of standard content, should also be digitized [14].

The development of standards digitization in Germany is inseparable from the Industry 4.0 strategy, and it is fully related to the process of industrial digitization from the perspectives of decision-making mechanisms, implementation modes, and industrial applications. Germany had established a ternary decision-making governance structure dominated by Standardization Council, Labs Network, and Industry 4.0 Platform [34]; and has set up a working group to promote the application of digital technology. Using the series Industry 4.0 specifications of *Details of the Asset Administration Shell* [29,35,36], a standards integration model that could be directly used on the cyber-physical systems (CPS) was constructed to describe enterprise assets in the digital world (Fig. 2). At this stage, Germany has gradually shifted the focus of standards digitization to the digital twin field to meet its rapidly developing research and application requirements [37].

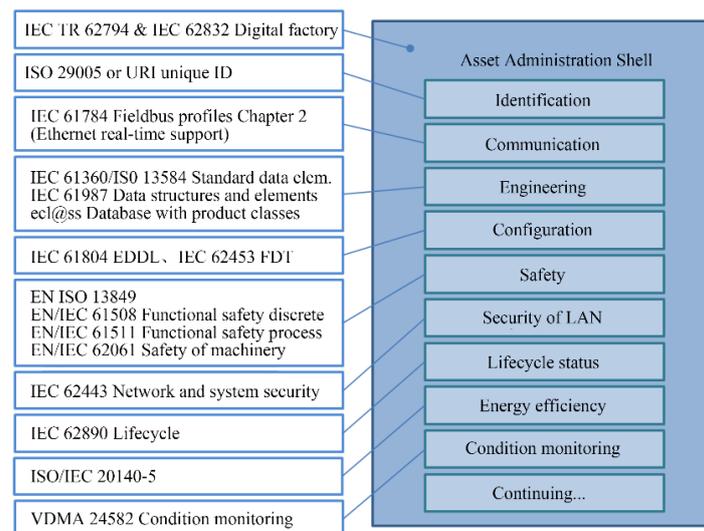


Fig. 2. Possible standards involved in German Industry 4.0 Asset Administration Shell.

Note: URI, uniform resource identifier; ID, identification number; VDMA, German Mechanical Engineering Industry Association.

3.2 Domestic development status

After long-term standardization practices and situation tracking research, China has seen the great significance of standards digitization, and some institutions have gradually carried out standards digitization research. Domestic research focuses on three aspects: content semanticization. For example, the National Library of Standards has studied and developed a Chinese and foreign standard content index comparison system based on semantic recognition technology and rich standard data [38]; The application of the knowledge graph in the field of standards, such as the IEEE standard p2959 *Standards for Technical Requirements of Standard-Oriented Knowledge Graphs* [39] proposed and approved by China Electronics Standardization Institute; Standard digital data sets, such as GB/T 22373-2021 *Metadata of Standard Literature* [40] led by the China National Institute of Standardization, and specific digital tag sets of standards drafted by some industry institutions.

The development of standards for technologies related to standards digitization (machine-readable, knowledge graph, etc.) in China is mainly completed by the National Technical Committee of Information and Documentation (TC4) and Information Technology (TC28). However, its development is still in the initial stage of standards digitization in China, which is the structuring and electronization of paper standards. There has been no systematic research on standards digitization, and no targeted national technical committee or subcommittee has been established.

4 Development trend of standards digitization

4.1 The standards content returns to the essence of knowledge and forms the ontology of standards knowledge.

The extraction, classification, and expression of standards content knowledge are realized using semantic modeling, artificial intelligence, visualization, and other technologies; where the massive standards text is transformed into a freely usable dynamic knowledge network. The use and mutual understanding of standards knowledge by human-machine or machine-machine is achieved through the construction of the ontology of standards knowledge. Accordingly, to interact with machines, the content arrangement, expression, quotation, format, and even semantic logic of the standards, need to be updated considering the digitization. Natural language will no longer be the only carrier of standards knowledge since standards expressed in machine language may be present. In fact, some relevant open-source projects of digital standards have emerged in the open-source community GitHub [16]. The Association for Supply Chain Management also launched the framework version of the Supply-Chain Operations Reference model (SCOR), called SCOR Digital Standards [41] in 2020. This will have an impact on the existing standardization conceptual system, principles, and methods. Presently, the main understanding of Digital Standards is that the machine-readable and interpretable standard developed in the digital environment is composed of a set of function-related data and instruction sets, which means that text standards and digital standards may coexist in some fields and scenarios in the future (such as CPS and digital twin).

4.2 Standards are more open, shared, and intelligent, forming an open-source standardization mode.

The open-source mode of standardization will affect the whole lifecycle of standards. On one hand, digital technology enables all stakeholders to develop standards and share information in real time. The standards development pattern was transformed from the original one-by-one and step-by-step to an overall and parallel pattern. This shortened the development cycle while changing the entire working mode of standardization. The COVID-19 pandemic has further promoted this trend. On the other hand, the acquisition and use of standards will also be more intelligent and direct; where the rapid retrieval and intelligent push of knowledge can be realized without downloading and reading a large number of texts. It can also be directly compiled into work instructions or rules through the machine, which directly affects the business process (such as certification and accreditation). In addition, the single-payment purchase pattern of the standards will also change.

4.3 Digitization brings new governance challenges to the standardization field.

With the development of standards digitization, the popularity and use of standards is more extensive, and the influence of open-source communities and standardizing organizations can be further enhanced. At this stage, the demand for standards digitization is concentrated only on the information and communication technology, financial technology, and data industries; however, existing organizations have begun to build a digital standards framework in the field of social governance to publicly collect information [15]. The acquisition, processing, and use of information in the collection process, may cause a series of governance and ethical issues such as intellectual property rights, data security, and privacy protection. The disposal of such problems will serve as a new proposition in the research on standards digitization.

5 Thoughts and suggestions

Standards digitization focuses on dealing with the impact of digital technology to promote the digital transformation of standardization. China's standards digitization is still in its exploratory stage; thus, it is necessary to integrate existing resources in combination with the current level, research basis, and field needs of

standardization. Taking positive actions in the working mechanisms, scientific research, pilot demonstrations, and international exchange; a solid standards digitization foundation for economic and social development can be built.

5.1 Establishing a special organization for standards digitization

The organization is mainly responsible for formulating China's development plan for standards digitization, which promotes relevant work corporately and coordinately to provide guidance and decision-making suggestions for standards digitization in the future. Specific working institutions should include relevant government departments, scientific research bodies, enterprises, public institutes, and professional technical organizations.

5.2 Conducting research on standards digitization theories and technology

The national science and technology policy and plans should guide the research on common and key technologies of standards digitization and solve common problems such as relevant theories, methods, and models; as well as key problems such as semantic recognition, data analysis, and rule integration in field applications.

5.3 Cultivating the industrial application of standards digitization

Further expansion of the pilot scope around the standards digital generation mechanism and application scenarios is required. The fundamental demand for standards digitization comes from its practical applications. By expanding the pilot and demonstration, we can explore broader standards digitization application methods (such as standard knowledge graphs and standards knowledge service platforms) and deeper standards digitization innovation (such as the in-depth application of artificial intelligence and big data technology in standards development and implementation).

5.4 Deepening international cooperation and exchanges on standards digitization

China has begun to appoint experts to participate in the research on digital transformation strategies and machine-readable standards of international standardizing organizations, such as ISO/IEC. However, owing to the late commencement of standards digitization, there is a gap between China and advanced organizations and countries. It is necessary to actively participate in international standardization work and activities around relevant themes, to strengthen the exchange of research results and practical experience, and to cultivate an international team of professionals to assist in accelerating the digitization process of China's economy and society.

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