

Smart Manufacturing Standardization: Reference Model and Standards Framework

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Abstract. With the progress of world trade and globalization, and the development of information & communication technology (ICT) and industrial technology, manufacturing pattern and technology are now facing a turning point. In order to realize economic transformation, the Chinese government published China Manufacturing 2025 national strategy; German government published Industry 4.0; and American government proposed Re-industrialization and Industrial Internet. All of these mentioned strategies have a key topic: smart manufacturing. In order to present a systematic standard solution for smart manufacturing, standardization organizations of China, Germany and US published standards landscapes or roadmaps. This paper compares these smart manufacturing standardization architectures and methodology, develops a reference model for smart manufacturing standards development and implementation. At the end of the paper, a standards framework is presented.

Keywords: Smart manufacturing, industry 4.0 · Industrial internet · Standardization

1 Introduction

With the progress of world trade and globalization, and the development of information & communication technology (ICT) and industrial technology, manufacturing pattern and technology are facing a turning point. Lots of developed or developing countries published their national strategies to support their economic transformation, which include:

- Integration of Industrialization & Informatization (iI&I) and Manufacturing 2025 of China;
- Industry 4.0 of Germany;
- Re-industrialization and industrial internet of US.

In the past 30 years, the development of China's industrialization has made remarkable achievements, and China industrialization makes a great contribution to the global economic growth. As shown in Fig. 1, since the Chinese industrialization

process is accompanied with the informatization progress, it is neither feasible nor necessary for China to follow the traditional development pattern (i.e. realizing industrialization first and then informatization). China should grasp tremendous historic opportunity which is brought by the ICT rapid development. Two historical processes (informatization and industrialization) are promoted together and mutually in China.

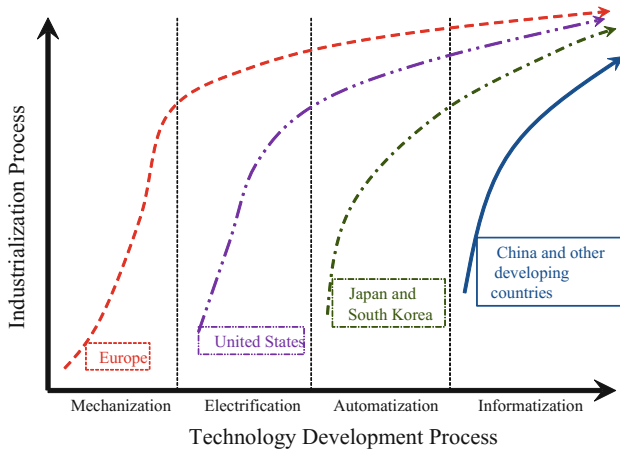


Fig. 1. Industrialization process with technology development process

Faced with the current complicated international and domestic economic situation and trends, the *iI&I* with smart manufacturing is a critical factor related to survival and long-term sustainability of Chinese enterprises. The *iI&I* in Chinese enterprises has its own characteristics. According to China's industrialization and ICT application status and shortcoming, in-depth exploration and practice should be started. In order to support manufacturing industry transformation, standardization is the important part of China's manufacturing technology development strategy, which includes several activities:

- Introducing and translating ISO/IEC standards into Chinese;
- Developing sets of technique standards;
- Developing standard framework for industrial enterprises;
- Develop management architecture and relative management standards.

German manufacturing industry and American manufacturing industry are facing the same transformation progress. In order to realize their national manufacturing development strategies, standardization landscapes were proposed. From this perspective, the significance of the standards is demonstrated.

Standards are the building blocks that provide for repeatable processes and the composition of different technological solutions to achieve a robust end result. With standards, business owners may be able to adopt technologies and innovations more easily. Also, standards raise innovations and can protect them, providing a sustainable

environment for the smart manufacturing, which, to be specific, means standards make the goals through improve the reliability of the system, relevance of the market and the security of the investment.

Without the support of standards, the process of implementing ICT can be rough, which may be costly and cause overwhelming waste of manpower and material resources because of those repeat research and survey. Standards allow people to work on the basis of the previous work did by experts or explorer, so without standards, the green hands in a certain industry may have huge difficulty in carrying out their work. Especially, during the process of informatization, the standards are the key of effectiveness of information exchanging, sharing and integration. Realizing the significance of the standardization, the paper compares these smart manufacturing standardization architectures and methodology, develops a reference model for smart manufacturing standards development and implementation. At the end of the paper, a standard framework is proposed.

2 Smart Manufacturing Standardization Review

Smart manufacturing integrates information technology, industrial technology and human creativity to push a rapid revolution of manufacturing pattern and technologies. It will fundamentally change process and pattern of product invention, design, production, shipping and sales. The targets of smart manufacturing are:

- Improving worker safety;
- Protecting the environment;
- Keeping manufacturers competitive in the global marketplace.

Standardization is an important tool to achieve the goal of smart manufacturing. Some standardization organizations develop their roadmaps for smart manufacturing standardization, following are the most remarkable three:

- National Institute of Standards and Technology (NIST) published “Current Standards Landscape for Smart Manufacturing Systems” [1].
- DIN, DKE VDE published “German Standardization Roadmap Industry 4.0” [2].
- Ministry of Industry and Information technology of China (MIIT) and Standardization Administration of China (SAC) published a joint report “National Smart Manufacturing Standards Architecture Construction Guidance” [3].

In order to point out developing trends of smart manufacturing, classifying and positioning all relative standards and describe relationships among standards clusters, the three reports all introduce into reference models.

As shown in Fig. 2(a), based on ARC Advisory Group’s collaboration manufacturing management model [4] and ISA95’s enterprise – control system integration hierarchical model, NIST describes the smart manufacturing ecosystem. Based on the ecosystem model, NIST’s standardization architecture includes 4 dimensions:

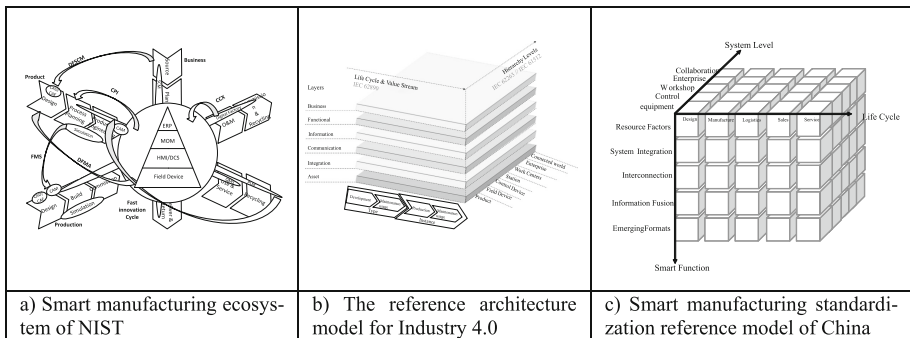


Fig. 2. Smart manufacturing reference architectures

- Product: standards along the product lifecycle from design, process planning, production engineering, manufacturing, use & service, to EOL & recycling.
- Production: standards along the production system lifecycle from design, build, commission, operation & maintenance, to decommission & recycling.
- Business: standards through the supply chain cycle from plan, source, make, deliver to return.
- Manufacturing pyramid: standards aligned to the ISA95 model - enterprise level, manufacturing operations management (MOM) level, supervisory control and data acquisition (SCADA) level, device level and cross levels.

Some current standards related to smart manufacturing are classified and arranged into some standards groups along the four dimensions. NIST’s report points out that current standards have not cover all areas of smart manufacturing.

The reference architecture model for Industry 4.0 is shown in Fig. 2(b). There are three dimensions to define the development directions of industry 4.0:

- Layers: from asset, integration, communication, information, functional, to business.
- Life cycle & value stream: from development to maintenance/usage which is defined by IEC 62890.
- Hierarchy levels: from product, field device, control device, station, work centers, enterprise, to connected world defined by ISO/IEC 62264 and IEC 61512.

Standards situation analysis, standard requirements analysis, and standard application analysis are discussed based on the reference model shown in Fig. 2(b).

In order to realize the Chinese Manufacturing 2025 national strategy, the Ministry of Industry and Information technology of China (MIIT) and Standardization Administration of China (SAC) published a joint report “National Smart Manufacturing Standards Architecture Construction Guidance”. In the report, the Smart manufacturing standardization reference model of China is shown in Fig. 2(c). It includes three dimensions:

- Smart functions: from resource elements, system integration, interconnect, information convergence, to new business models.
- Life cycle: from design, production, logistics, marketing and sales, to service.
- Hierarchy levels: from device, control, plant, enterprise, to inter enterprise collaboration.

From above discussion we can get that the key standardization global design methodology for smart manufacturing is:

- To define or reference a reference architecture model for smart manufacturing.
- To classify and position standards in multiple dimension systems.
- To analyze current status, requirements, and application of standardization progress.

Although the three reports share some common ideas and similar concepts/elements, it is necessary to develop a general reference model for smart manufacturing standardization:

- A generalized reference model is needed to link the above mentioned reference models together to realize interoperation among these models.
- In the above mentioned reference models, standards are located on every dimension. How to develop and use standards cover two or three dimensions, especially in the NIST report, has not discussed in detail.
- There are different viewpoints for standards development and implementation, how to combine them together is a big challenge.
- For a manufacturing company, it is necessary to accept and apply a standard framework as a whole to support their smart manufacturing program. Therefore, how to describe standards clusters as a system is required.

Based on industrial models and system reference architectures, the paper develops a smart manufacturing standardization reference model and the relative framework.

3 Smart Manufacturing Standardization Reference Model

For a manufacturing enterprise, how to use smart manufacturing technology and management principles to link manufacturing processes together is the core consideration. Based on SIMA reference architecture Part 1 Activity model [5], which divides the ICT application process in an enterprise into Design Product, Engineering Manufacture or Product, Engineer Production System, Produce Products, and Manage Engineering Workflow, the reference model of ICT application along research, development, and manufacturing whole lifecycle is shown in Fig. 3, in which we can see main activities of research, development, and manufacturing, as well as ICT's supporting to these activities.

- For R&D activities, CAD, CAE, and CAPP are involved. CAD, CAE, CAPP and CAM are step by step interconnected and integrated. PDM is implemented to integrate all design applications together.
- For manufacturing activities, from physical layer, MES layer to business layer, multiple layers of the manufacturing pyramid shall be integrated.

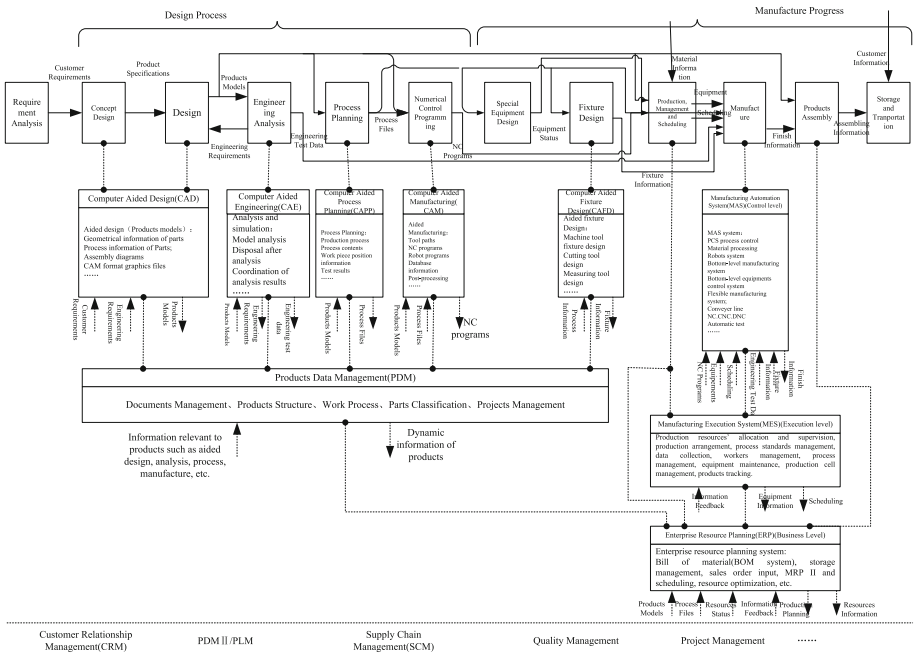


Fig. 3. ICT application relationship along R&D & manufacturing whole lifecycle

- For business operation activities, there are four information systems: enterprise resource planning (ERP), supply chain management (SCM), customer relationship management (CRM), and product lifecycle management (PLM). Some additional information systems, such as BI, are integrated with the four systems.

In order to guide ICT application and integration, it is necessary to analyse and describe relationship among technologies. From the viewpoint of ICT application, ICT application reference architecture model shall consider about requirements of enterprise collaboration and integration, and realize following two kinds of integration:

- From bottom level automation system, through manufacturing excursion system, to decision supporting. All layers of an enterprise shall be integrated, and then the integrated system shall be extended to integrate from suppliers to customers (the whole value chain), and realize inter enterprises collaboration.
- Because informatization relates to multiple enterprise business fields, including research, development, production, service, decision and so forth. ICT application reference architecture model shall consider the whole business/value chains.

Therefore, the analysis dimensions of ICT application architecture and reference model can be defined into two aspects as shown in Fig. 4:

- ICT application layers;
- Life cycle and value stream.

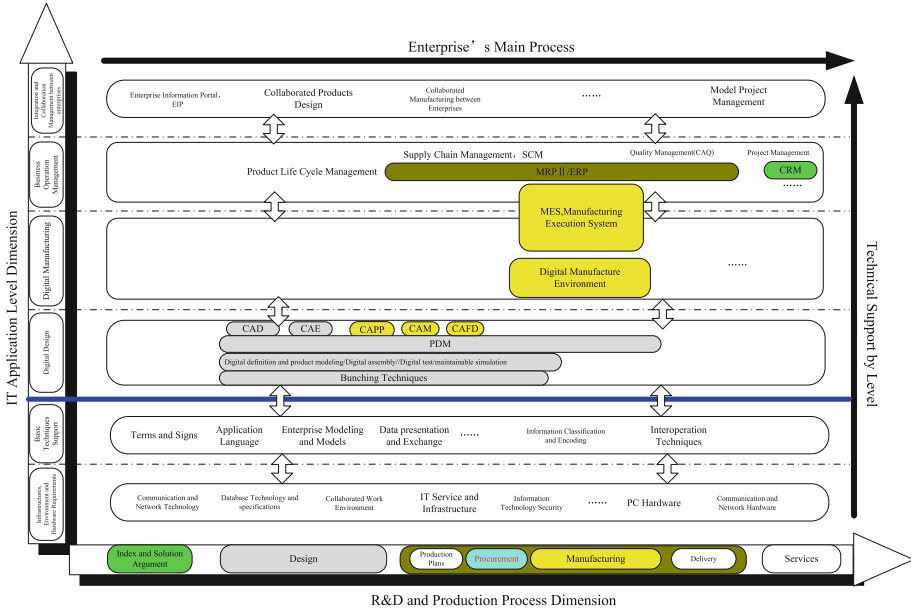


Fig. 4. ICT application architecture

In the Fig. 4, the first dimension relates to ICT application technologies and their functional hierarchical decomposition, which includes smart design technology, manufacturing technology, business operation and management technology, system integration technology, fundamental technology and supporting environment. The second dimension relates to product design and manufacturing whole life cycle, which includes solution argument, design, plan, purchase, production preparation, production, use and maintenance.

According to characteristics of standardization, Fig. 4 shall be adjusted as follows:

- The decomposition of technologies used by business operation and management is not based on current information systems (i.e. ERP, PLM, SCM, CRM and so forth), but based on management fields, which include design management, manufacturing management and business management. Thus can avoid focusing on information system commercial products and keep the relative stability of standardization framework. Application problems of information systems are classified into the combined management.
- Integration technologies are not located among functional technologies. For example, they are not classified as 3C integration, PDM & ERP integration. They are classified as integration interface, interoperability, integration platform and so forth based on the common properties of integration technologies.
- Manufacturing process is divided into production preparation and manufacturing excursion, supported by smart manufacturing environment.

Figure 5 is the resulted ICT application standardization reference model.

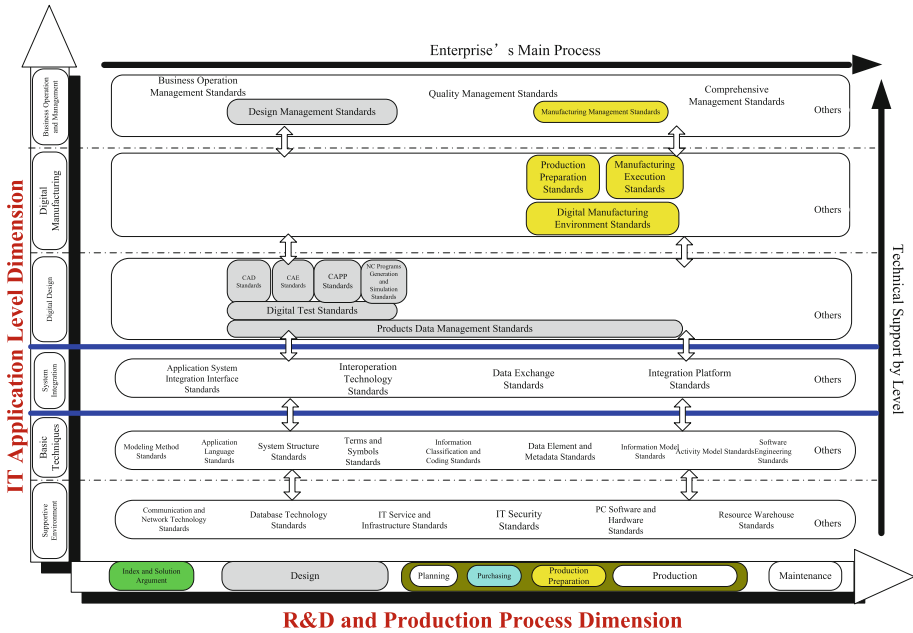


Fig. 5. ICT application standardization reference model

4 Smart Manufacturing Standard Framework

Based on the ICT application standardization reference model, the ICT application standards framework can be derived by methodology below:

- To derive the basic structure elements according to the application domain decomposition of ICT.
- To formulate the basic framework in two dimensions: ICT application layers and Life cycle/value stream.
- To locate the elements technology in the domain, integration technology, basic technology and support environment in the framework, and then determine the basic ICT standards.
- To build relevant standards according to those ICTs.
- To generate the detail branches iteratively.

So the ICT application standards framework can be derived, which is shown in Fig. 6.

- Smart design standards: the group of standards are expanded along the order of design activities, supported by data management standards. The standard framework decomposition does not follow the classification of design subjects.
- Smart production standards: the group of standards are expanded based on working process and technical supporting.

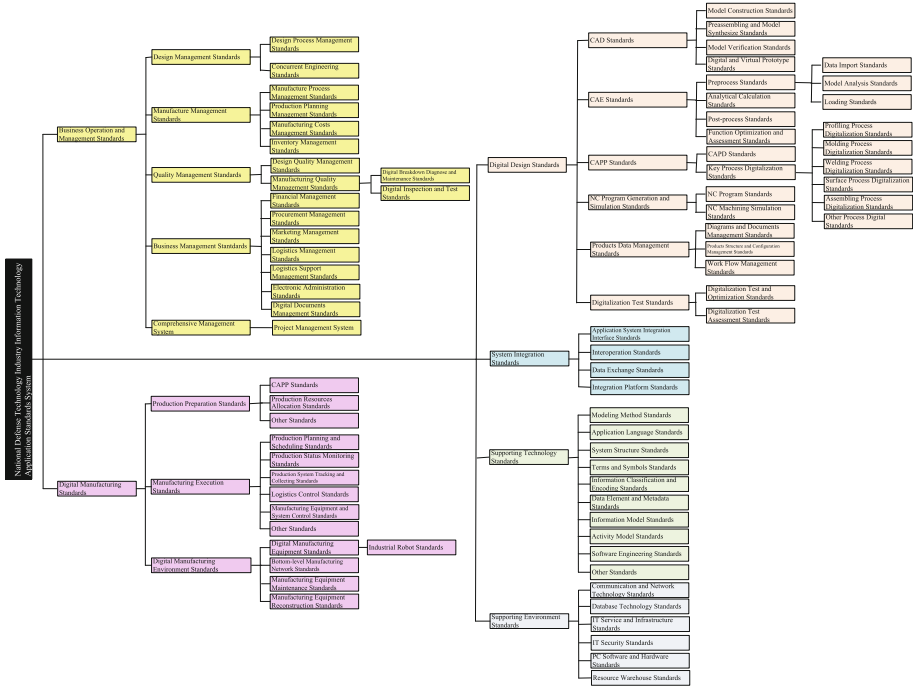


Fig. 6. ICT application standard framework

- Business operation and management standards: the group of standards are focused on management activities for design and production. ERP, SCR, CRM, MES, these commercial applications are not used as standards categories. Their implementation standards are discussed in combined management standard group.
- System integration standards: the group of standards relate to common technologies that integrate systems of different domains. They are classified based on technical types but integration software.
- Fundamental technologies and supporting environment standards: the group of standards includes standards on common supporting technologies, such as infrastructure, database, meta data technology and so forth.

5 Summary and Conclusion

Smart manufacturing is a systematic technology, which relates to ICT, industrial technology and management technology. Smart manufacturing system is a huge scale complex system. Standardization is a powerful tool to push the development and implementation of smart manufacturing technologies.

NIST, DIN, MIIT&SAC published standards landscape, standardization roadmap, or standardization construction guidance for smart manufacturing. Currently existing

standards are arranged in relative reference model and reference standardization reference architecture. Based on results of these reports, the paper develops a reference model for smart manufacturing standards development and application. An ICT application standard framework is also developed.

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