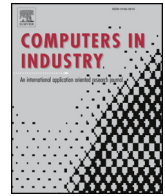




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Smart manufacturing standardization: Architectures, reference models and standards framework



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ABSTRACT

With the development of information & communication technology (ICT), industrial technology and management technology, manufacturing operation pattern and technology are improving quickly. In order to realize economic transformation and get their national competitiveness, American government proposed Re-industrialization and Industrial Internet, German government announced Industry 4.0, and Chinese government published Made in China 2025 national strategy. All of these mentioned strategies have a key topic: smart manufacturing. ISO, IEC, ITU, IEEE, and other international standard development organizations (SDOs) develop sets of international standards related to smart manufacturing. In order to present a systematic standardization solution for smart manufacturing, SDOs of the US, Germany, China and other countries developed their own national standards landscapes or roadmaps. In the paper, the new development of ICT and industrial technology are reviewed firstly. Then, these smart manufacturing architectures are analysed and compared. Thirdly, the reference model for smart manufacturing standards development and implementation is developed. At the end of the paper, a standards framework is provided.

1. Introduction

With the development of information & communication technology (ICT), industrial technology and management technology, manufacturing pattern and technology are improving quickly. Two historical processes, informatization and industrialization, are promoted mutually.

As shown in Fig. 1, because of different indoctrination levels, different countries are facing different challenges of informatization. Based on technical advantages, developed countries try to keep or resume their manufacturing competitiveness. Since newly industrialized countries and developing countries' industrialization process is accompanied with the informatization process, it is neither feasible nor necessary for these countries to follow the traditional development pattern (i.e. realizing industrialization first and then informatization). Newly industrialized countries and developing countries hope to grasp tremendous historic opportunity which is brought by the ICT rapid development.

In the context of informatization and industrialization, some developed and developing countries announced their national manufacturing strategies to support their economic transformation and

national competitiveness.

- The United States published *A Framework for Revitalizing American Manufacturing* in December 2009 [1] and *National Network for Manufacturing Innovation: A Preliminary Design* in January 2013 [2]. Re-industrialization, the third industrial revolution, industrial internet, smart manufacturing are key concepts of national manufacturing strategies of the United States.
- Germany published *Recommendation for Implementing the Strategic Initiative INDUSTRIE 4.0* in April 2013 [3]. Now, Industry 4.0 is a hot topic discussed and researched by governments and industrial enterprises all over the world, in which Internet of Things (IoT), Cyber-Physical Systems (CPS) and smart manufacturing are the key concepts.
- Chinese government announced *Special Action Plan for Deep Integration of Informatization and Industrialization (2013–2018)* in Aug. 2013 [4] and *Made in China 2025* in May 2015 [5]. Integration of informatization and industrialization (II&I), smart manufacturing and industrial internet are placed in important positions in Chinese national strategic plans.
- Japan announced the Industrial Value Chain in June 2015 [6]. A

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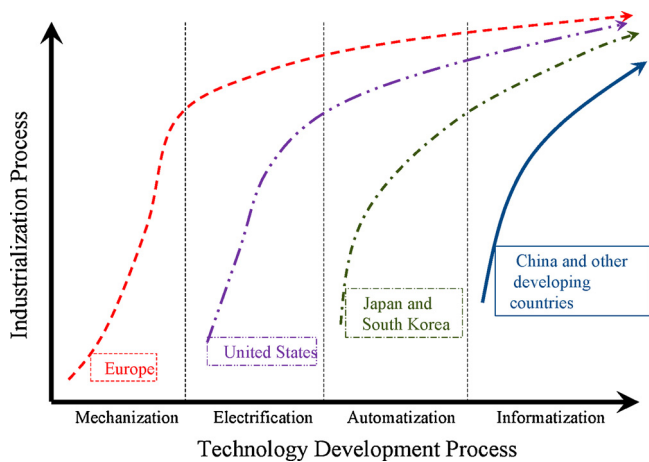


Fig. 1. Industrialization process with technology development processes [8].

new organization, Industrial Value Chain Initiative (IVI), has been set up.

- The Government Office for Science and Department for Business, Innovation & Skills of UK sponsored the Foresight project and published *The Future of Manufacturing* serial reports in October 2013 [7]. The foresight project developed a long-term picture for the UK manufacturing sector between 2013 and 2050.

Above mentioned strategies include different terms: Industry 4.0, smart manufacturing, industrial Internet, intelligent manufacturing, and so forth. Although some literatures discuss differences of these terms [9], in the paper, we do not distinguish the difference among these terms. Based on comparative studies [10,11], all of these terms share the same connotation and can be concluded into one key topic: smart manufacturing.

Manufacturing is the multi-phase process of creating a product out of raw materials. Smart manufacturing aims to take advantages of advanced information and manufacturing technologies to enable flexibility in physical processes to address a dynamic and global market [12]. Because smart manufacturing naturally has features of information technology, manufacturing (industrial) technology and their integration, it can be considered as one of implementation paths of ii&i.

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 manufacturing enterprises. In order to support manufacturing industry transformation and update, standardization is the important part of smart manufacturing strategies all over the world.

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 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 smart manufacturing will be rough. It may also be costly and cause overwhelming waste of manpower and material resources due to the repetition of research and surveys. Standards allow people to work on the basis of the previous work conducted by experts. So without standards, new comers in a certain industry may have huge difficulty in carrying out their work. Especially, during the process of informatization, standards are the key of effectiveness of information exchanging, sharing and integration [13]. Kim, Lee and Kwak make an investigation of M2M (machine-to-machine) and IoT standards and patents, and conclude that standards serve as a driver of technological convergence.

They also find related technology or system architectures lead the development of standards, which serve as a critical factor in the process of creating a new path for catch-up firms [14,15].

In order to realize the significance of the standardization, the paper firstly reviews the development of technologies and smart manufacturing, and then compares main smart manufacturing architectures. The reference model for smart manufacturing standards development and implementation is developed later. Finally, a standards framework is proposed [8].

2. Smart manufacturing and related standardizations

In the past 40 years, ICT develops very quickly and it is integrated with manufacturing activities deeply. There are several dimensions to help us to understand manufacturing technology improvement as well as ICT.

- Computing centre is transferring from machine oriented, to application oriented, and then to enterprise-oriented computing.
- Integration scope is extended from single computer usage, to department application and integration with LAN, to enterprise application and integration with WAN, to inter enterprises application and integration with the Internet, and then to enterprise network collaboration and supply chain network integration [16].
- Enterprise infrastructure is changing from mainframe, to client / server (C/S), to browser / server (B/S), to SOA (service-oriented architecture) and then cloud computing [17].
- The capability of enterprise information system, which evolves from office automation system (OA), to management information system (MIS) [18], to material requirement planning (MRP), to manufacturing resource planning (MRPII), to enterprise resource planning (ERP), and then to collaboration manufacturing / business and supply chain management, is increasing [16].
- Computing aided designing tools have emerged to CAD (computer aided design), CAE (computer aided engineering) [19], CAM (computer aided manufacturing) [20], CAPP (computer aided progress planning) [21], PDM (product data management), PLM (product lifecycle management), collaboration simulation, virtual reality (VR) [22] and so forth.
- Service Oriented Architecture (SOA) [17], cloud computing [23], wireless sensor network and smart technology, mobile network [24], IoT [25,26], semantic web, big data [27], 3D printing technology, CPS [28], artificial intelligence and so forth, these new emerging technologies are integrated with manufacturing more and more deeply and quickly.
- Manufacturing patterns transform from craft manufacturing, mass production, computer integrated manufacturing (CIM), lean production [29–31], agile manufacturing [32], next generation manufacturing (NGM), to smart manufacturing, Industry 4.0 and industrial Internet. Including total quality management (TQM) [33], business process re-engineering (BPR) [34], management technologies are also developing quickly.
- Industrial / manufacturing technology is also developing quickly. New equipment, new material, new production process and new energy technology make many breakthroughs. For instance, 3D printing (additive manufacturing) technique is a new manufacturing method, which is the convergence of new equipment technology, material technology and ICT.

Smart manufacturing converges information technology, industrial / manufacturing technology, management technology and human/organization to push a rapid revolution in the development and application of manufacturing intelligence. It will fundamentally change features of manufacturing.

- It will change products inventing, manufacturing, shipping and

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