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Smart manufacturing technology, market maturity analysis and technology roadmap in the computer and electronic product manufacturing industry

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ABSTRACT

Through a survey and analysis of the available literature, this paper briefly depicts the background of the development of Industry 4.0 (i.e., Smart Manufacturing) and corresponding industry development policies of various major countries. A smart manufacturing key technology architecture is proposed to classify nineteen key technologies as belonging to a sensor layer, an integration layer, an intelligent layer or a response layer. A technology roadmap is developed as the framework and key technologies are defined through expert interviews which provide insight into Taiwan's current status of smart manufacturing, including market maturity, technology maturity and correlation of key technologies, and these correlation results are organized in a correlation matrix. Suggestions for future Taiwan smart manufacturing industry development were also solicited from experts. Based on the results, this paper proposes a prediction of Smart Manufacturing domain technology and market maturity as well as emerging technology development trends. Based on this analysis of smart manufacturing domain technology and market trends, the results provide a foundation for industry and researchers to understand the development trends for key smart manufacturing technologies, and for policy formulation to support industry development.

1. Introduction

Information and communication technology (ICT) systems are critical to modern manufacturing. The Forth Industrial Revolution (Industry 4.0) integrates all current technologies such as sensors, wireless networks, Internet of Things (IoT), robotics, artificial intelligence and information management systems to create a Cyber-Physical System (CPS) and smart factories (Jang, 2016; Kang et al., 2016; Lee et al., 2015). Industry 4.0 refers to a number of automated systems equipped with automatic data exchange and manufacturing technology capabilities. These systems exert a transformative effect on economic and social processes. Recently, Industry 4.0 concepts have attracted considerable attention in advanced manufacturing countries as a means of streamlining production.

Industry 4.0 is thus not a completely new area of research, but builds upon previous research and ties together recent advances in the areas of automation, artificial intelligence, production technology, information communication technology, and cloud technology (Kagermann et al., 2013; Lee et al., 2015). A key component of Industry 4.0 is the concept of smart manufacturing. According to the National Institute of Standard and Technology, NIST (2014), Smart Manufacturing is defined as "fully-integrated and collaborative manufacturing systems that respond in real time to meet the changing demands and conditions in the factory, supply network, and customer needs."

Smart manufacturing is driving a push towards enhanced competitiveness among manufacturers worldwide. According to PwC's "2016 Global Industry 4.0 Survey," the global manufacturing industry will invest more than US$900 billion in Industry 4.0 initiatives by 2020. In 2015, 33% of global enterprises surveyed in the report considered themselves to be highly digitized, but this ratio is expected to increase to rise to 72% by 2020. Global manufacturers are digitizing key functions of their internal horizontal value chains and external vertical supply chains, and these digital innovations are expected to help enterprises reduce costs by 43% and increase revenues by 35% (PwC, 2016).

According to the World Economic Forum's, 2014–2015 Global Competitiveness Report, Taiwan is the world's most concentrated IT industry cluster, and is the world's second-largest exporter of high-technology manufactured goods, reflecting Taiwan's high degree of hardware/software integration, creating conditions for flexible production and rapid commercialization. In 2015, Taiwan's government

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unveiled a plan called "Productivity 4.0" and earmarked over US$1 billion for investment over nine years to transform sectors such as technology, machinery, and transportation. By 2024, this plan aims to raise the per capita productivity of Taiwan's manufacturing industries by 60% to NT$10 million (Prakash, 2016). In addition, building on Taiwan's solid foundation of precision machinery and ICT technologies, Productivity 4.0 is pushing the development of Smart Machine solutions in an integrated industrial ecosystem (Taiwan Executive Yuan, 2015).

In our study, smart manufacturing technologies are categorized as belonging to a sensor layer, an integration layer, an intelligent layer and a response layer. A technology roadmap is developed as a context for the analysis of correlations between technology applications and industry maturity. Technologies were defined through interviews with industry experts, and the correlation results are used to create a correlation matrix for the current status of smart manufacturing in Taiwan, including market maturity, technology maturity and correlation of key technologies. Suggestions for future smart manufacturing industry development in Taiwan were also collected. This paper analyzes technology applications related to smart manufacturing and emerging trends. Analysis of authentic cases illuminates the development of technologies related to smart manufacturing in a range of countries, and market and technology maturity trends for each technology are discussed in the context of Taiwan. This paper aims to provide a foundational understanding of key technology development trends for industry while serving as a useful reference for the formulation of government policy to support industrial initiatives.

2. Industry 4.0

The industrial revolution of 1712–1912, referred to as, Industry 1.0, introduced steam engines and enabled the development of machine based production in the UK and Germany. Industry 2.0 (1913–1968) was characterized by the development of mass production powered by electrical energy. Industry 3.0 (1969–2012) introduced electronic devices and information technologies, which allowed for the automation of industrial manufacturing. Industry 4.0 (2013-) is a Cyber-Physical System (CPS) that applies the virtual networks to physical factories to enhance manufacturing production based on data analytics. Internet-of-Things technologies vertically and horizontally integrate entire industries, providing real-time feedback as well as application analysis. Industry 4.0 also makes feasible high variety and low volume custom manufacturing. Large scale deployment of Industry 4.0 techniques and practices are expected to be in place by 2020 (Kagermann et al., 2013).

The 4th Industrial Revolution, Industry 4.0, is derived from the German term "Industrie 4.0" which was announced at the 2011 Hannover Fair. This initiative focuses on the integration of ICT hardware and software for CPS, and the topic has attracted increasing attention around the world. Through technology convergence, Industry 4.0 is expected to improve existing major manufacturing practices in terms of productivity, quality and flexibility, and will have a significant impact on work and daily life, along with increasing the global income levels (DFKI, 2011).

Various major manufacturing countries have adopted different policy approaches to respond to and promote Industry 4.0. The United States has focused on 3D printing, big data management, manufacturing systems and intelligent robots. Japan is seeking to revitalize its economy through equipment investment and R&D. China is upgrading its manufacturing industry with the aim to become a world manufacturing power by 2025. Other major countries are actively building agile and reliable cyber-physical systems for smart manufacturing, production and marketing to respond to market demand. Appendix A summarizes Industry 4.0-related initiatives in major industrial countries.

Foidl and Felderer (2016) discussed potential opportunities for Industry 4.0 in the context of an Austrian electronic manufacturing services company. They also raised related research challenges for quality management based on the DIN ISO 9000 quality management systems approach and categorized as either vertical, horizontal or end-to-end engineering integration. Kang et al. (2016) surveyed and analyzed various articles related to Smart Manufacturing, predicted future development trends, and analyzed the policies and technology roadmaps of Germany, the U.S., and Korea to identify networked sensors, data interoperability, multi-scale dynamic modeling and simulation, intelligent automation and scalable and multi-level cyber security as key emerging technologies.

Stock and Seliger (2016) presented a comprehensive review of recent Industry 4.0 developments, along with an overview of the main trends and expected development for different value creation factors in Industry 4.0. Chen and Tsai (2017) examined the success factors for the implementation of ubiquitous manufacturing (UM), a "design anywhere, make anywhere, sell anywhere, and at any time" paradigm, which emphasizes the mobility and dispersion of manufacturing resources and users based on advances in sensing, communication and networking technologies. Furthermore, they conclude that UM is a realizable target for Industry 4.0. Wang et al. (2016) focused on key algorithms used operate the smart manufacturing plants and proposed an intelligent negotiation mechanism to implement a self-organized manufacturing system, and proposed four deadlock prevention strategies used in the development of a smart factory prototype with algorithms for further system performance optimization.

3. Research methodology

The research methodology applied in this paper can be divided into three stages. First, a thirty smart manufacturing cases from various countries were collected through secondary sources. Common technologies used in current smart manufacturing case were identified and drawn as a technology roadmap in the second step. Based on the literature review and Taiwan Productivity 4.0 Technologies and applications used in each case were categorized as belonging to one of four sequential layers: Sensor, Integration, Intelligent, and Response. The completeness of all key smart manufacturing technologies reviewed by this research was also verified. The third step applied the Delphi method, inviting industry experts and researchers to define the technologies under review and predict future trends. Experts were also asked to comment on technology and market maturity, along with technology development correlation trends to generate a technology correlation matrix. Based on these results, this research provides predictions regarding smart manufacturing technology and market maturity and technology correlation development, along with sample roadmaps for technology development, which could serve as a reference for government support and industry R&D.

3.1. Technology roadmap

Technology roadmaps are a method used in the medium and long term planning for new technology development to meet particular business objectives, and are widely used in technology innovation (Amadi-Echendu et al., 2011; Lee and Park, 2005; Phaal et al., 2004). Technology roadmap help organizations plan technology development through articulating descriptions of related technologies, products and market paths. It is also used for technology trend prediction. By analyzing current technology status and customer needs, technology roadmaps can provide useful information about alternative technologies, competitors and prospective market entrance timing. They can also be used to explore correlations among organization objectives, organizational technology resources and ever-changing market opportunities (Lee and Park, 2005; Phaal et al., 2004; Rinne, 2004).

A technology roadmap is often comprised of three major layers (Phaal et al., 2010). The upper layer includes driving factors related to trends, overall objectives and market demand. The middle layer