INTELLIGENT MANUFACTURING MANAGEMENT SYSTEMS

OPERATIONAL APPLICATIONS OF EVOLUTIONARY DIGITAL TECHNOLOGIES IN MECHANICAL AND INDUSTRIAL ENGINEERING

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Preface

Since the world is no longer reliant on analogue technology, the new standard, which is digital, is centered on the management of data, which has become the equivalent of industrial gold in this century. The examination of this data has a great many applications in the business world, ranging from retail enterprises to medical applications and supply chain management, amongst other areas, and can be used to forecast various aspects of consumer behavior such as product utilization and consumer requirements. With the current improvement in IoT applications, the utilization of data has progressed beyond these fundamental economic applications at this point. Because of this digitization, information is now being shared on a massive scale, to the point where there is now an intelligent information system that connects industry, machines, and even end-users across a wide range of devices, which, when structured, models the physical world.

The collection of a wide variety of datasets, collectively referred to as "big data," is now much simpler thanks to the widespread use of internet-based technology. In most cases, this data is obtained via social media, shopping data, and the purchasing habits of consumers, among other sources. Understanding behaviors and conducting predictive analysis could both benefit from this information. Using artificial intelligence (AI), large amounts of data may be easily interpreted for the sake of strategic planning. The majority of the machinery and tools used in manufacturing industries come equipped with sensors and make use of the internet for the purposes of monitoring as well as data transfer. Artificial intelligence, with its growing capacity for machine learning, could be combined with these features to drive the manufacturing industry. This could be put to use for a broad variety of economic purposes, including the management of maintenance based on data analysis, the making of decisions, the planning of efficiency improvements, remote management, automation of industrial lines, and data visualization, to mention a few. Because of this, it is clear that even though IoT collects a lot of data from equipment, sensors, and other sources, the large amount of data creates an analytical bottleneck that could be solved by using AI to quickly evaluate and understand the data in real time.

The concepts that pertain to the application of digital evolutionary technologies in the sphere of industrial engineering and manufacturing are presented in this book. A few chapters of the book demonstrate these concepts with stepwise discussion, case studies, structured literature review, rigorous experimentation results, and applications. A few chapters also attempt to address the challenges encountered by industries in integrating these digital technologies into their operational activities as well as the opportunities for this integration.

The ideas and concepts addressed in this book will be useful to professionals, researchers, academics, and undergraduate and graduate students in non-circuit fields, particularly those majoring in mechanical engineering, industrial engineering, and business studies. So, this book offers practicing engineers, stakeholders, and academics a better way to move toward Industry 4.0.

The Editors
February 2023

Part I

SMART TECHNOLOGIES IN MANUFACTURING

1

Smart Manufacturing Systems for Industry 4.0

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Abstract
Manufacturing industries have evolved from using of steam power for mechanization to using of electricity in the past two industrial revolutions. The third industrial revolution was brought about with the application of information technology in manufacturing. Now, it has reached the fourth industrial revolution or Industry 4.0 which is built on inter-connectivity. Smart manufacturing systems play an integral role in moving towards Industry 4.0. The aim of this chapter is to discuss the technologies which supports and contributes to smart manufacturing and to understand its characteristics. Because of the benefits of smart manufacturing, it has attracted various professionals to apply smart manufacturing in their own fields. In this chapter, the applications of smart manufacturing are presented especially in industrial and mechanical engineering. The challenges faced by the industry while implementing smart manufacturing systems has also been mentioned.

***Keywords*:** Industry 4.0, additive manufacturing, smart manufacturing system, big data analytics, machine learning, CPS, IoT, cloud manufacturing

Abbreviations

CPS	Cyber-Physical System
DT	Digital Twin

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AI	Artificial Intelligence
NIST	National Institute of Standards and Technology
AM	Additive Manufacturing
CAD	Computer Aided Design
ANN	Artificial Neural Network
IoT	Internet of Things
CNC	Computer Numerical Control
PdM	Predictive Maintenance
AMCoT	Advanced Manufacturing Cloud of Things
RFID	Radio Frequency Identification
GPS	Global Positioning System
GIS	Geographic Information Systems
VR	Virtual Reality
AR	Augmented Reality
SMTS	Smart Machine Tool System
DQN	Deep Q Network
SMKL	Smart Manufacturing Kaizen Level
FAHP	Fuzzy Analytic Hierarchy Process
SMMEs	Small, Medium and Micro-Enterprise

1.1 Introduction

Smart manufacturing systems aid in transforming traditional industry into an intelligent and interconnected manufacturing system through technologies like Cyber-Physical Systems (CPS), Digital Twin (DT), Artificial Intelligence (AI), etc. Due to its network, it enables a shift from centralized to decentralized manufacturing units [1]. Manufacturing technology is merged with information technology via an interface so as to connect the local intelligence with the system intelligence [2]. Smart Manufacturing is mostly about the methods of improving processes and decisions within industrial manufacturing environments [3].

The National Institute of Standards and Technology (NIST) defines smart manufacturing as "fully-integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs". Smart manufacturing systems are implemented with the objectives of providing autonomous lean operation and co-development of multi-stakeholder and smart manufacturing systems enterprise by sharing of knowledge and information [4]. Moreover, it should have the characteristics of self-learning, self-optimizing, and adaptability to the change in manufacturing environment [5].

The study on smart manufacturing systems for Industry 4.0 has been carried out to help the readers specially beginners, in understanding the concepts as well as the broad structure of Industry 4.0. It will aid the researchers to advance the work or to implement Industry 4.0 in the manufacturing system. Given the diverse nature of smart manufacturing, existing scientific literature does not provide a clear understanding of this topic as most researchers either work on a specific domain or on a particular enabling technology. Therefore, this study aims at filling this gap by covering the broad scope of smart manufacturing.

This chapter will brief the eight pillars of smart manufacturing which are sustainability, data, manufacturing technology and processes, materials, predictive engineering, resource sharing and networking, stakeholders and standardization [2]. Various cutting-edge technologies and solutions has been developed under each pillar which supports and contributes to smart manufacturing. For simplicity, such enablers will be grouped under five categories i.e., smart machining, smart control, smart design, smart monitoring, and smart scheduling [6]. The enablers will be discussed in detail along with their applications in Industrial and Mechanical Engineering. Assessment of smart manufacturing system as well as the challenges faced by the industry while implementing smart manufacturing systems has also been discussed.

Smart manufacturing is not only about the technologies that are associated with it but it's about how the data are collected, captured, analyzed and communicated so as to make the best decisions in real-time. Because of the benefits of smart manufacturing like energy efficiency, greater productivity and its ability to tackle the competitiveness of the industry, it is applied in the fields of aviation, manufacturing, healthcare, building management, automotive industry, etc. The chapter will finally end with the implications of the study for academicians and practitioners, followed by concluding remarks and contribution of this chapter.

1.2 Research Methodology

The main purpose of this study is to provide a basic knowledge of smart manufacturing system in context of Industry 4.0. In order to obtain that, a systematic mapping process [7] was applied in this study. This research methodology was chosen as it provides a broad overview of the research area.

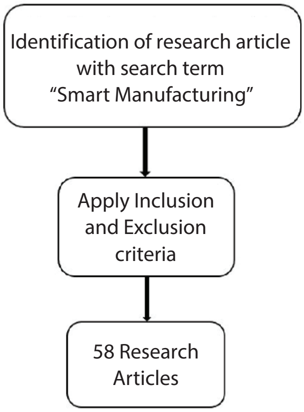

Figure 1.1 A schematic representation of the research methodology.

The schematic representation of the research methodology used in this study is shown in Figure 1.1. The first step was to identify the search term required for finding the research articles. The research papers were chosen from three leading digital databases; Science Direct, Google Scholar and IEEE Xplore. A total of 77 articles were identified from the four databases. It was followed by processing of papers using a set of inclusion and exclusion criteria. To be included in the study, the search terms should be present in the articles and it should be from an academic source. While the exclusion criteria involve removing duplication from those papers which met the inclusion criteria as well as omitting those papers that does not align with the topic of the study. As a result, 58 papers were found to be relevant for this study.

1.3 Pillars of Smart Manufacturing

The nature of smart manufacturing can be expressed across eight pillars [2]. Each pillar is described in the following section.

1.3.1 Manufacturing Technology and Processes

A manufacturing unit with intelligent control technology is reliable as it gives accurate products and can quickly respond to changes namely, market changes, fluctuations in load, and uncertain conditions, etc. [8]. Smart manufacturing technology like additive manufacturing (AM) enables the fabrication of complex component directly from its Computer Aided Design (CAD) models. Because it is a material addition process, parts can be manufactured using exotic materials. Traditional manufacturing has its own advantages which cannot be overlooked. As a result, hybrid of additive and traditional processes will produce a quality product as it will exploit the benefits of both the processes. Manufacturing equipment can be made smarter with an addition of sensor and robots along with integration of several operations.

Manufacturing of precision components from sheet metal coil requires levelling before performing metal forming/cutting process so as to remove the residual stress which was left from the coil. Expert machine technicians choose the machine parameters based on their experiences. So, Tsai *et al.* [9] digitize the knowledge of expert technicians on coil leveling system through deep learning method, originated from Artificial Neural Network (ANN). ANN is an information processing paradigm where knowledge is acquired through a learning process similar to the way the brain process information [10].

Due to the availability of numerous smart manufacturing solutions, Martin *et al.* [11] developed a methodology based on value stream mapping method. It supports the production planner to choose the best solution for a given manufacturing system.

1.3.2 Materials

Smart manufacturing utilizes all sort of materials which includes smart materials, organic-based materials, and biomaterials. This enables the engineers to take advantage of their unique properties in creating a component. Smart materials use sensors to detect unwanted changes in environment and operations, while the required corrective actions are carried out by actuators [12]. The sensors used for smart manufacturing systems (CPS, Internet of things (IoT), robot-human interactions) are multi-material sensors as single material sensors are not enough for such applications [13].

Smart manufacturing is not directly involved in the development of novel materials but it led to exploration of new materials as almost all materials could be fabricated. Although there are some materials which require novel processes to be developed for its fabrication. Making use of recycled materials as raw materials will reduce the amount of products which are discarded at the landfills after their end of life.

1.3.3 Data

Data plays a major role in smart manufacturing. It could be considered as the building block of smart manufacturing system. Data are of various kinds such as vibration data, visual data, auditory data, etc. It is collected from diverse sources like sensors, wireless technology, analytics, and so on. The data are being collected for various purposes such as, productivity analysis, building predictive models, preserving and extraction of information related to manufacturing, etc. This ultimately results in tremendous amount of data production. Such large sets of data including real-time data could be analyzed using a technology called big data analytics [8].

The data can also be analyzed using data visualization technique where data are represented by means of graphs or other visual representations. After converting the data into useful knowledge, it could be used to develop decision, predictive and diagnostic models. Moreover, the study of real-world system could be simplified by analyzing the data generated from the simulation of a model.

1.3.4 Sustainability

Sustainability in manufacturing is essential in safeguarding the environment as well as in increasing the resource efficiency. Sustainability is not only about what product is manufactured but it should also include re-manufacturing, product usage impacts, surface restoration, supply chain energy costs, and waste disposal [14].

Sustainability efforts include sustainable product design, using environment friendly materials or biodegradable or recycled materials as raw materials, development of manufacturing processes which consume less energy and release fewer pollutants. As a matter of fact, AM is a sustainable manufacturing process as it generates less scrap and it could perform surface as well as geometry restoration. To reduce energy consumption in Computer Numerical Control (CNC) shop floor for stamping dies, an identical parallel machine scheduling problem was studied by Wang *et al.* [15] and developed an efficient method. Blömeke *et al.* [16] identified smart manufacturing technologies and solutions such as, smart bin, automated transport system, pick by vision, and cobots to support companies in carrying out recycling and remanufacturing operations. In a system which involves human-robot collaboration, protective measures could be given to the human component by connecting it with adaptor technologies for tracking safety distance or human position [17].

1.3.5 Resource Sharing and Networking

Resource sharing and networking is one of the capabilities of smart manufacturing systems that set it apart from other manufacturing system. Exchange and sharing of information between the system units enables interoperability within the system [8]. Storing data digitally for instance, in cloud, which behaves like a database, allows sharing of resources across businesses in an instant. In a manufacturing network, computational and physical resource efficiency can be increased using an intelligent cloud manufacturing platform [18]. Adoption of IoT enables smart manufacturing to carry out collaborative modelling, lease manufacturing equipment, share software and expertise, etc.

Transportation in manufacturing, though a non-value-adding activity, is an essential part of manufacturing. Autonomy in material handling, supply and distribution network can be increased with developments in robotics and autonomous vehicles. Whereas sharing of resources digitally will reduce the overall transportation cost.

1.3.6 Predictive Engineering

Predictive engineering provides manufacturing solutions by enabling machines and systems or material handling and transportation vehicles to make their own decisions. This is made possible due to the adoption of smart sensor networks, smart machines and smart vehicles. It utilizes advanced prediction tools for processing the data into information that gives an insight into future performance of the equipment. This will reduce the impact of uncertainties on the quality of manufactured products and services as solutions can be implemented to prevent performance loss [19].

A manufacturing system which responds and recovers autonomously to disturbances in real-time could manage to lower the downtime of the system. But Predictive maintenance (PdM) could be a better process as it involves correcting future critical conditions which are predicted using both current and past machinery data [20]. Implementing PdM reduces the cost associated with defective products and downtime. For PdM, a multiple classifier machine learning methodology was applied on a semiconductor manufacturing Ion-Implanter by Susto *et al.* [21] for related maintenance related task. It resulted in reduction of operating cost and better performance. A case study was carried out by Lin *et al.* [22] in a semiconductor company in Taiwan, where a smart manufacturing platform-AMCoT (Advanced Manufacturing Cloud of Things) was applied to a bumping process. It has the capabilities to conduct total inspection, detect the root cause of yield loss, store and handle production data, and provide predictive maintenance on the equipment.

1.3.7 Stakeholders

Smart manufacturing stakeholders consists of manufacturers (managers, employees), suppliers (system integrators, material, software, energy and hardware suppliers), communities (local and government communities), and customers. With an advancement in technology like AI, cloud computing and big data, stakeholders' requirement could be predicted and fulfilled [23]. In smart manufacturing system, co-development of enterprise and its multi-stakeholder is a must [4]. Smart manufacturing system will evolve depending on the optimization of stakeholders' value.

Intelligent tracking technologies like Radio Frequency Identification (RFID), Global Positioning Systems (GPS), wireless telecommunications, and Geographic Information Systems (GIS) improves customer services. Using such technology in supply chain provides accurate information and a visual experience to the related stakeholders. Moreover, stakeholders are involved in the creation of sustainable products and services. Due to the manufacturing system moving towards automation, reduction in jobs for low-skilled laborers will indeed take place. Conversely, demand for employees with competencies in software development and IT technologies will rise due to the increasing use of analytics, software, and connectivity [24].

1.3.8 Standardization

Standards are fundamental for the implementation and development of smart manufacturing system. Availability of standards eliminate the loss cause by repetition of research. In addition to that, developing common standards is useful to form or to operate smart manufacturing supply networks. Around 30 standards related to smart manufacturing systems have been published [25]. Standards come in varieties so as to enable the various capabilities of smart manufacturing system [26]. The standard of smart manufacturing system includes [27]:

1. Smart design standards which deal with design activities and data management.
2. Smart production standards focused on the working processes.
3. Business operation and management standards focused on management activities for design and production.