The International Journal of Advanced Manufacturing Technology (2019) 105:3565–3577
https://doi.org/10.1007/s00170-019-04595-0

EDITORIAL

Design and management of digital manufacturing and assembly systems in the Industry 4.0 era

Yuval Cohen[1] · Maurizio Faccio[2] · Francesco Pilati[3] · Xifan Yao[4]

Received: 18 June 2019 / Accepted: 21 October 2019 / Published online: 18 November 2019
© Springer-Verlag London Ltd., part of Springer Nature 2019

Abstract
The advances in Industry 4.0 provide both challenges and opportunities for digital manufacturing and assembly systems. This paper first addresses the state-of-the-art readiness for Industry 4.0 concerning assembly and manufacturing systems through a literature review of the relevant papers recently published. Then it assesses the challenges faced nowadays by assembly and manufacturing systems. Third, it focuses on the most promising future developments and evolution of such production systems as well as their digitalisation. Finally, this manuscript illustrates the content of the papers selected for this special issue. Through the study presented in this special issue, valuable contributions to both theory and application in this area have been achieved, and a useful reference for future research is given.

Keywords Industry 4.0 · Smart manufacturing · Factory of the Future · Assembly line · Cyber-physical production system · Internet of Things · Artificial Intelligence · Additive manufacturing · Predictive maintenance · Digitalization · Digital Twin · Framework · Editorial · Review

1 Preface

The manufacturing environment radically changed over the last decades. These changes are still in progress and are a result of integrating numerous breakthrough innovations in various technologies, such as big-data analytics (e.g. deep-learning, data-mining), enhanced computer vision, friendly robotics, communications and Internet of Things (IoT), smart self-aware sensors and systems, and the cloud virtually limitless memory and computing power. Manufacturing change has been facilitated by the ubiquitous use of cheap sensors and actuators communicating through the Internet, leading to real-time connection between systems, machines, tools, workers, customers and products defining the so-called IoT [1]. The enormous quantity of data (e.g. Big Data) generated by these connected objects represents the raw material of twenty-first century. IoT allows to develop a novel production paradigm, called personalized production which enables the customer involvement since the product design phase [2]. The market demand evolution over the last decades requires high volumes of products individually personalized [3]. This recent revolution of the industrial environment is named "Industry 4.0" (I4.0) which represents the comprehensive transformation of the entire industrial production through the merging of Internet, and information and communication technologies (ICT) with traditional manufacturing processes [4].

Purpose of I4.0 is the development of a new generation of smart factories grounded on the manufacturing and assembly process digitalization [5]. Smart factories of I4.0 era are distinguished by an increased production flexibility thought the use of real-time reconfigurable machines that allow the profitable personalized production of products in batches as small as the unique item [6]. A remarkable opportunity to target these goals is the development of a brand new generation of manufacturing and assembly systems implementing the I4.0 principles to production processes [7].

✉ Francesco Pilati
francesco.pilati@unitn.it

1 Department of Industrial Engineering, Tel-Aviv Afeka College of Engineering, Mivtza kadesh St, 38 Tel Aviv, Israel

2 Department of Management and Engineering, University of Padova, Stradella San Nicola 3, 36100 Vicenza, Italy

3 Department of Industrial Engineering, University of Trento, via Sommarive 9, 38123 Trento, Italy

4 School of Mechanical & Automotive Engineering, South China University of Technology Guangzhou, Guangzhou 510640, China

"Digital Manufacturing and Assembly Systems" are modularly structured with embedded cyber physical modules such as "smart assembly stations", "self-aware reconfigurable machines" and "smart assemblies and parts". Not only these elements are aware of each other and themselves, they communicate and cooperate with each other in real time, integrating the physical processes with virtual information to eliminate errors and maximize the production process efficiency. Furthermore, aided assembly improves the duration and safety of fastening and picking activities through several technologies, as cobots, computerized numeric control (CNC) machines, and reconfigurable tools, which are integrated through adequate controls in an open architecture environment to produce a particular family of customized parts ensuring a scalable, convertible and profitable manufacturing process.

The subject of this special issue is the design and management of "Digital Manufacturing and Assembly Systems" for an efficient, flexible and modular production of customized products exploiting the I4.0 enabling technologies. Examples of the related published manuscripts subjects are proper automation technologies, ICT infrastructures, control algorithms, optimization models, management and design methods as well as industrial case studies for the new generation of "Digital Manufacturing and Assembly Systems".

The remainder of this paper is organized as follows. Section 2 proposes the state-of-the-art readiness for Industry 4.0 concerning assembly and manufacturing systems presenting a literature review of the relevant papers recently published concerning the digitalization of these production systems. Section 3 assesses the challenges faced nowadays by assembly (Section 3.1) and manufacturing (Section 3.2) systems, whereas Section 4 focuses on the most promising future developments and evolution of such production systems as well as their digitalisation. Section 5 illustrates the content of the papers selected for this special issue. Finally, Section 6 presents major remarks for further research.

2 State of the art readiness for Industry 4.0

Ever since the industrial revolution, the manufacturing industry evolution has always been driven by new technologies that facilitate improvements such as increased throughput, lower costs and reduced downtime [8]. Moreover, modern production systems have to manage the product lifecycle reduction, product mass customisation, the growth in product variety and the reduction of the time to market [3, 9]. The recent confluence of technologies culminating in I4.0 is a significant step toward increasing throughput, lowering costs and reducing downtime. I4.0 represents the comprehensive transformation of the entire industrial production to an age where machinery and parts would possess not only awareness of their status through the merging of Internet as well as ICT with traditional manufacturing processes [4].

According to GTAI [10], I4.0 represents the technological evolution from embedded systems to cyber-physical systems (CPS). In I4.0, embedded systems, semantic machine-to-machine communication, IoT and CPS technologies are integrating the virtual space with the physical world. IoT allows to develop a novel production paradigm, called personalized production which enables the customer involvement since the product design phase [7]. The final challenge is to create the so-called Smart Factory, an intelligent industrial context in which all the elements are integrated together and communicate in real time. The emergent behaviour of such an integrated assembly or manufacturing system, at both intra- and inter-organisational levels, is indeed the I4.0 environment. This emergence of I4.0 has been fuelled by the recent development in ICT. The developments and the technological advances in I4.0 will provide a viable array of solutions to the growing needs of computerisation and digitalisation in manufacturing industries.

The scientific research is almost pouring contributes describing I4.0 new automation technologies, ICT infrastructures, control algorithms, optimization models or industrial case studies for the new generation of assembly and manufacturing systems.

Currently, it is instead focused on two main directions (Fig. 1):

- The definition of the new manufacturing and assembly paradigms within the I4.0 era, with the aim of defining the new manufacturing and assembly concepts and principles.

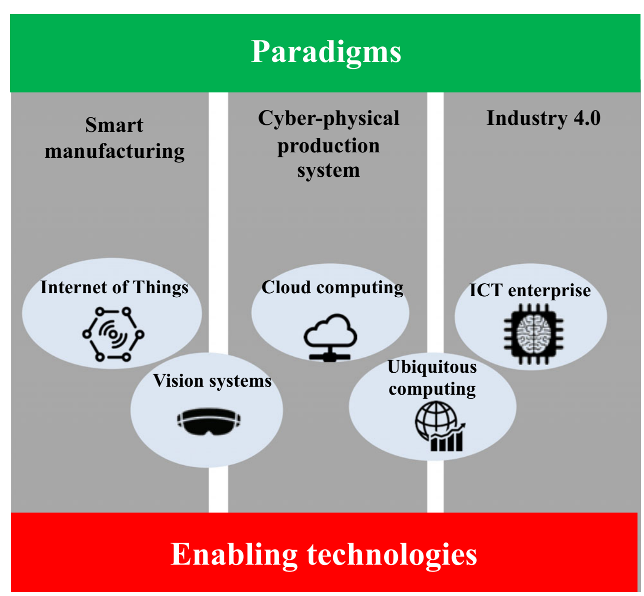

Fig. 1 Manufacturing and assembly paradigms as well as enabling technologies of I4.0 era

- The definition of the enabling technologies for the development of the I4.0 paradigms with the aim of showing the state of the art and highlighting the novelty in the ICT development.

This section will explore these two research directions. However, the coverage is by no means meant to be exhaustive, but a representation of the actual state of the art.

2.1 Manufacturing and assembly Industry 4.0 paradigms

A number of new paradigms have emerged in recent years in an attempt to describe the requirements and characteristics of the next generation of manufacturing and assembly systems [8]. This variety of paradigms, which is rooted in the different/competing viewpoints of various researchers, initiatives and organizations, must be reduced as it hinders the creation of a consistent goal and transition plan. More often than not, these paradigms are used as synonymous in describing the next generation of manufacturing and assembly systems. Some of the widely discussed paradigms in manufacturing and assembly include the following:

- Smart manufacturing [11], defined 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.
- Cyber-physical production systems (CPS) [12], defined as a transformative system that translates data from interconnected system into predictive and prescriptive operations to achieve resilient performance. It deploys digital twin technologies to support the life cycle of products.
- I4.0 [10], it is defined as those products and services flexibly connected via the internet or other network applications like the blockchain. The digital connectivity enables an automated and self-optimized production of goods and services including delivering without human interventions. The value networks are decentralized controlled while system elements take autonomous decisions.

It is important to highlight, even if it is not the focus of this paper, that even services are included [8]. The common objectives of all the paradigms previously discussed are to make mass-personalization a reality, to provide customers with smart and sustainable products and services, and to enable real-time adaptation for dynamic changes of customer demand, factory settings and supply/value networks.

2.2 Enabling technologies

Various technologies or techniques can be used for implementing I4.0. According to the Boston Consulting Group [13], I4.0 includes nine enabling technologies to support this paradigm implementation within an industrial context: (1) Advanced Manufacturing Solutions, (2) Additive Manufacturing, (3) Augmented Reality, (4) Simulation, (5) Horizontal/Vertical Integration, (6) Industrial Internet, (7) Cloud, (8) Cyber-security, and (9) Big Data and Analytics. On the other hand, the scientific literature summarises these technologies in different ways [8, 14] presented as follows:

- IoT

  The term IoT refers to the robust communication between digital and physical worlds. From this viewpoint, IoT brings the convergence of connected products and sensors to offer new competence [15]. When the term IoT first emerged, it was referred to uniquely identifiable interoperable connected objects using radio-frequency identification (RFID) technology [16]. Connecting RFID reader to the Internet, the readers can automatically and uniquely identify and track the objects attached with tags in real time. Later on, the IoT technology was used with other technologies, such as sensors, actuators, the Global Positioning System (GPS) and mobile devices that are operated via Wi-Fi, Bluetooth, cellular networks or near field communication (NFC). Other relevant key technologies for IoT are barcodes, smart phones, location-based service, service oriented architecture (SOA), near field communication and social networks [17].
- Vision systems

  Even if this technology is not often cited, its utilisation is becoming wide, both in human and robotised production systems. The use of vision systems to reproduce physical processes into digitalised processes is used in robotics since at least one decade. One of the first application was a vision system integrated with a control software that gives the robot arm the exact coordinates of the components to pick in an automatic assembly system [18], later extended with the possibility to recognize different components increasing the flexibility of the proposed solution [19, 20]. Recently, the use of vision systems to digitalise manual production processes has been proposed using Motion Capture (MOCAP) technology [21]. Marker-based optical MOCAP exploits active or passive markers properly displaced in specific part of human body, using the IoT technology. However, this system has different drawbacks, especially if applied to the manufacturing and assembly context. Marker-less optical MOCAP represents a recent advance in the technology, freeing the operator to perform his activities [21]. Through this technology, it is possible to digitalise the human activity and to automatically and quantitatively measure the work content of the considered manual tasks through an accurate motion and time analysis within different industrial activities (such as manufacturing, assembly, human-machine interaction and warehousing) [22].

- Ubiquitous computing

  A virtual computer model can be seamlessly integrated with physical networks of objects [23]. Ubiquitous computing is enabled by smart devices, which are capable of integrating devices, organisations, and information systems for data sharing and exchange; real-time monitoring; and using anything, anywhere, anytime communication to sense, capture, measure and transfer data. For individual smart devices, their performance has been improved greatly.
- Cloud computing

  The enormous quantity of data (e.g. Big Data) generated by these connected objects represents the raw material of twenty-first century. Cloud computing is a computing technology which offers high performance and low cost [24]. Virtualization technology provides cloud computing with resource sharing, dynamic allocation, flexible extension and numerous other advantages. A large volume of data can be uploaded to a cloud computing centre for storage and computation, which facilitates manufacturing and assembly. Cloud-based manufacturing is a rising technology which can contribute significantly to the realisation of I4.0 that enables modularization and service-orientation in the context of manufacturing [25].
- Cyber Physical System (CPS)

  Even if CPS is described also as a paradigm, it represents the core technological foundation of I4.0. In CPS, physical and software components are deeply intertwined, each operating on different spatial and temporal scales and interacting with each other in a myriad of ways that change with context [26]. Advances in CPS will enable capability, adaptability, scalability, resiliency, safety, security and usability that will far exceed the simple embedded systems of today manufacturing and assembly systems [27].
- ICT Enterprise architecture and application integration

  The ICT Enterprise architecture is represented by the set of ICT technologies able to manage its processes. The most adopted basic ICT technology is the organizational main information management system also known as Enterprise Resource Planning (ERP) system that helps companies to manage their business efficiently. New ICT is capable of integrating both new and classical industrial production processes. As organisations move past the hype surrounding digital transformation in I4.0, they face the complex realities of implementation ranging from introducing new CPS and smart factories technologies and applications to adapting or replacing core enterprise architectures, ICT infrastructures and processes [14]. Integration, consolidation and coordinated applications have been identified as a critical issue in the I4.0 environment. Weber [28] has pointed out that one of the most important issues surrounding I4.0 is the fact that existing equipment is not capable of communicating with newly deployed technology. This obstacle can be overcome by Enterprise Application Integration (EAI) system [14], which is created with different methods and on different platforms, aiming at connecting the current and new system processes, and providing a flexible and convenient process integration mechanism. The integration of enterprise applications includes the integration of heterogeneous data sources, processes, applications, platforms and standards.

3 Technology integration challenges for production systems

As presented in the previous Section, the current industrial environment is distinguished by the adoption of novel production paradigms, often overlapped or competing with each other, along with the development of radical innovations resulting in several promising enabling technologies. Furthermore, this environment is distinguished by the massive digitalisation of manufacturing and assembly processes which generate at high velocity a huge volume of data distinguished by a wide variety which could be leveraged to benefit of their hidden but remarkable value. All these aspects result in several challenges faced by current production systems. The following two subsections 3.1 and 3.2 further investigate the current challenges respectively for assembly and manufacturing systems.

3.1 Current technology integration challenges in assembly systems

Historically, assembly processes took a key part in the major industrial innovative advances. The Swiss famous fine hand assembly of the cuckoo-clocks was probably an early part of this tradition. Then in 1801, the assembly of 10,000 assault rifles by Eli Whitney heralded the age of standardization [29]. A hundred years later, Ford established the first car assembly facility which was the first mass production assembly facility [7]. During the twentieth century, assembly lines were the backdrop for the development of time and motion studies, ergonomics, statistical process control, multi-model scheduling, load balancing, and more recently automated guided vehicles (AGVs), RFID, GPS and mass customization [30].

As explained in Section 2, a confluence of several technologies that only recently made their way into the assembly lines is marking the basis for the new age of industry, namely I4.0. Assembly lines in the era of I4.0 are named “Assembly 4.0” [7]. In addition to the technologies mentioned in Section 2.2 (such as IoT, computer vision, and digital twins), the following is a brief summary of some technologies that are making their way into the assembly line shop floor [31] which has to be considered in addition to the more general purpose one presented in Sections 2.2 for the entire industrial environment:

- 3D printing

  In assembly processes, the printing of missing or defect parts enable avoiding delays, and the complications of logistics. 3D printing also enables printing special shape fasteners for assembly, or embeds the fastening ability within the shape of the printed part. 3D printing has made incredible advances in its abilities to rapidly print with various materials (including metals). Some applications of 3D printing are rapid prototyping, on demand part printing, personalized 3D printing (e.g. medical purposes) and broken-part replacements.
- Augmented reality (AR)

  AR future in assembly systems looks bright, and their capabilities and quality will undoubtedly increase with time [32]. AR enhances users' experience of the real world by embedding virtual objects to coexist and interact with real objects in the real world creating an augmented environment [33]. Assembly instructions given in Google Glasses or other media types are already making ways into assembly shop floors. However, a potential drawback is represented by the huge cognitive workload of assembly operators which adopt on daily bases AR solutions. The massive information quantity they receive in addition to the one perceived by natural human five senses could worsen, instead improve, their performances.
- Cobots

  Cobots are collaborative robots intended to physically work and safely interact with humans in a time- and space-shared working environment. Assembly lines and assembly systems are especially suited environment for cobots, since there are many opportunities for interacting and assisting the assembly manual work. The increased ability of robots along with elimination of safety issues, open new opportunities for cobot utilization in assembly lines [34]. Cobots in the assembly processes are used smartly to assist manual assembly work, replace the worker in awkward postures or even replace part of the manual movements. In that way, the assembly is done much better and faster.
- Autonomous mobile material handling vehicles

  The timely and safe mobilization of parts to their assembly stations is one of the fundamental logistic challenges of any assembly line or assembly system. Bringing the right part, in the right time, to the right assembly station has become even more challenging with the increase in mass customization. Both human driven trolleys and AGVs are used for this purpose. However, autonomous mobile material handling systems are expected to have wider adoption as material handling standard devices in assembly lines [35].
- Self-awareness of sensors, parts, machines and systems

  In assembly lines, most problems, defects and disruptions, may be avoided by the presence and deployment of self-aware, and self-healing sensors, machines and workstations. These systems are aware of their environment, perform real-time process monitoring and know every detail about their own mechanical component health [36]. Self-awareness is frequently mentioned along with self-diagnosis, self-prognosis and self-healing. Thus, in every assembly process, every development that may create failure or defect is detected early enough to make a correction and fix the problem.

These and other technologies are still evolving and experience is still gathered related to their application. Moreover, these technologies increase and enhance the capabilities and efficiency of assembly systems in which they are embedded. However, they also bring about major challenges. The following list identifies seven major technology challenges faced by current assembly systems:

- Bringing all the aforementioned technologies to materialize their full potential in assembly systems is a critical challenge. This requires the involvement of the technique specialists in the assembly line design and renovation process.
- The synergetic integration of existing technologies in the assembly lines is a crucial aspect. While it is clear and easy to see the advantage of applying each technology by itself in the assembly line, it is much less clear how combinations of these technologies may bring added value to the entire assembly system.
- Human/automation collaboration and automated assistance to the manual work of human workers is major challenge of assembly system of the I4.0 era. The optimal integration of humans and machines in the assembly system is still a relevant and open issue.
- The creation of an efficient assembly process for a large variety of products is still a question to be answered nowadays. This includes increased flexibility and adopting novel technologies (e.g. 3D printing, IoT) to enable such large variety of products to be mounted on the same assembly system with minimum reconfiguration.
- Material handling is an open issue for today assembly system. In particular, it is related to streamlining the flow of materials in the assembly systems despite their variety. Some facilitating technologies may be digital twin, IoT, machine learning, etc.
- The smart design of assembly systems is a crucial aspect of today production plants. This entails incorporating AI

and expert system assistance for better design of assemblies and sub-assemblies as well as their parts. The involvement of the customer starting with the product design phase goes into this direction and it is enabled by late customisation approaches along with the adoption of online 3D printing of components designed by the customer himself/herself to fulfil his/her unique need.

- The last challenge is to gather and keep the Assembly 4.0 human specialists, who focus on operating, maintaining, enhancing and developing the new Assembly 4.0 technologies. This may require knowledge from a wide range of fields: from IoT to cobots, from digital twins to 3D printing and from AR to computer vision.

The new digital technologies of I4.0 enable enhanced, efficient and more varied throughput of current mass production assembly lines. They facilitate the production of variety of products on the same assembly system. Cobots and virtual reality as well as additive manufacturing and 3D printing increase the productivity of assembly workers, and eventually save significant workforce. It is conceivable that these technologies will streamline material flow of specialized assembly systems (currently working as flow shops or job shops) into a discipline closer to a virtual assembly line.

As time goes by, more of the manual assembly operations are automated. However, the need for human technology specialists to maintain and operate the assembly machines is on the rise and shall continue to be so in the foreseeable future. The need for skilled and trained personnel to maintain and operate the assembly 4.0 systems is expected to remain high throughout I4.0 era.

3.2 Current technology integration challenges for manufacturing systems

Digital manufacturing originated in CNC in which machining utilized computerized controls to operate and manipulate machine and cutting tools to shape stock material. In turn, CNC evolved from the numerical control (NC) machining process that used punched cards to encode each movement in the 1940s [37]. CNC technologies form the core of computer-aided manufacturing (CAM). In the fields of design, engineering and manufacturing, such computer applications resulted in computer-aided design (CAD) and computer-aided engineering (CAE).

Computers play a key role in manufacturing digitalisation, but resulting in so-called “data silos” or “isolated data islands”. Such islands, e. g. computer aided technologies (CAX) such as CAD, CAM and CAE, are needed to merge. Historically, computer-aided process planning (CAPP) was emerged to improve the data exchange and management in the integration of CAD and CAM, and especially product data management (PDM) enhanced such integration to the data management of a product life cycle.

In fact, in the 1970s, flexible manufacturing system (FMS) and computer-integrated manufacturing system (CIMS) were proposed to integrate CAD, CAM, CAPP and MRP/MRPII as a whole. Later, such concepts as lean production (LP), concurrent engineering (CE), and agile manufacturing (AM) were further proposed to enhance or extend the idea of FMS/CIMS. In particular, Internet (Web 1.0) emergence in the 1990s made manufacturing integration globally possible, which enabled the data exchange and management from design to analysis to production and to service.

In the 2000s, Enterprise 2.0 was coined along with the emergence of Web 2.0, and cyber-physical systems were proposed. In the 2010s, next-generation intelligent manufacturing models such as smart factory (SF), cloud manufacturing, the Internet of manufacturing things (IoMT), smart manufacturing (SM), wisdom manufacturing (WM), cyber-physical production system (CPPS) and even social-cyber-physical production system (SCPPS) have been emerging [5, 38–41], as shown in Fig. 2a.

These smart manufacturing models based on emerging ICT and artificial intelligence (AI) [38, 39], especially WM and SCPPS that integrate Internet of People (IoP), IoT, Internet of Services (IoS) and Internet of Content and Knowledge (IoCK) [40, 42–44], generate a large amount of data-big data [45], as shown in Fig. 2b. Thus, big data processing as well as subsystem integration in digital manufacturing systems is a big challenge [46].

Actually, challenges faced by manufacturing systems are in some ways similar to those by assembly systems as discussed above. However, the former must be addressed from a broader viewpoint of systems engineering whereas the latter is usually part of the former. Therefore, in addition to those challenges by assembly systems, manufacturing systems further face the following challenges:

- Big data

  Manufacturing digitalisation along with the development of computers, ICT and AI, results in industrial big data, which brings 4Vs (Volume, Velocity, Variety and Value) challenges for manufacturing, and such big data processing is totally different from that focusing on structured data before.
- Integration

  There co-exist vertical integration, horizontal integration and end-to-end integration in CPPS/SCPPS, which challenge existing traditional vertical and/or horizontal integration, for example, in CIMS.
- Security

  As data collected for SCPPS involves physical devices, cyber services/digital twins, and social humans, measures must be taken to ensure equipment safety, digital piracy and personnel privacy.

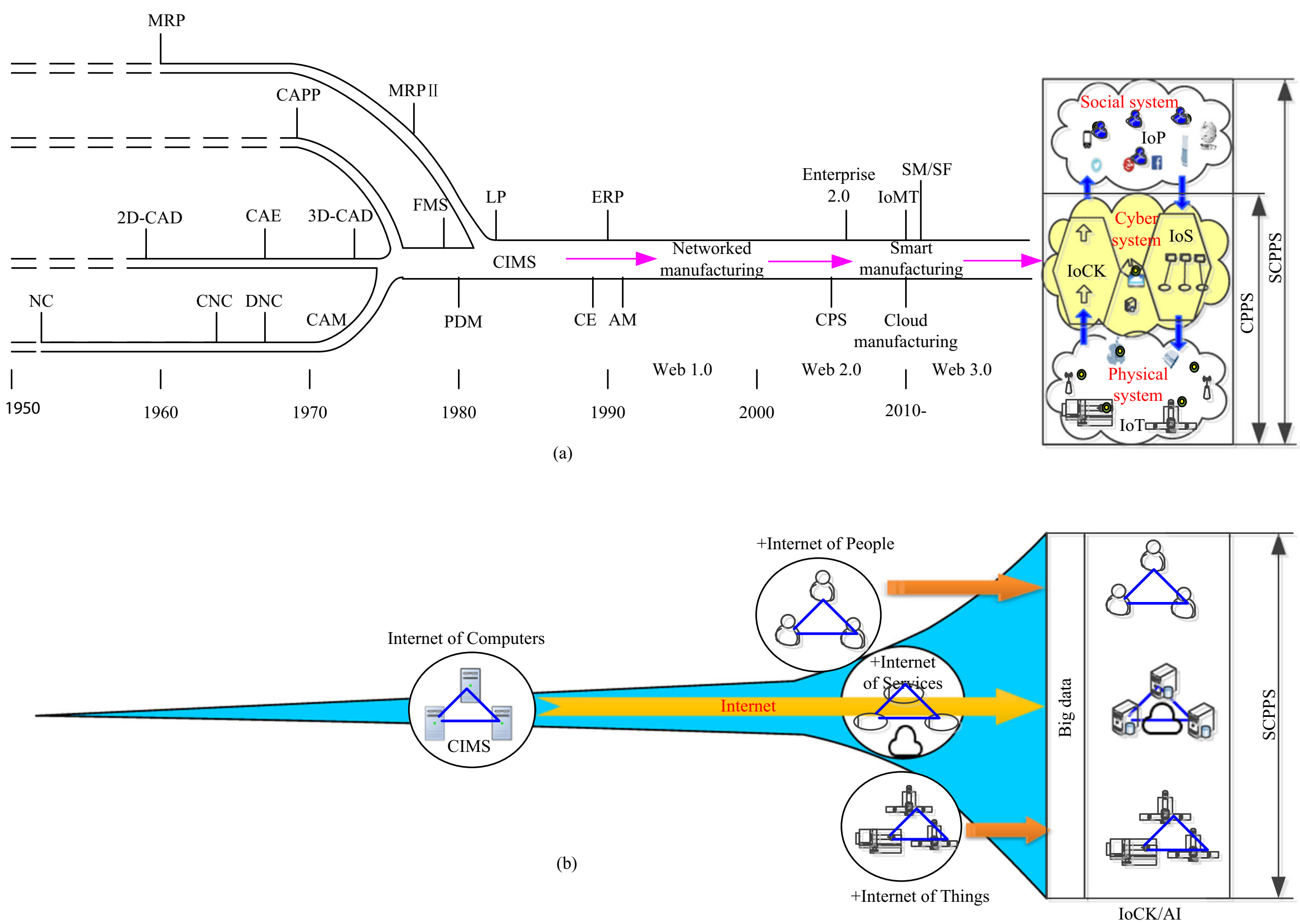

Fig. 2 Manufacturing digitalisation. **a** Manufacturing system evolution. **b** Digital data volume in manufacturing

4 Future trends and research agenda in digital manufacturing and assembly systems

This section presents the most promising future trends in the research of digital manufacturing and assembly systems, with the aim of defining the future roadmap in creating I4.0 implementation, integration and standardisation models. The current trends in research could be divided into two main directions: technical and organisational future trends.

4.1 Technical future trends

For many manufacturing companies, the existing ICT infrastructures are not entirely ready to support the digital transformation to I4.0 which aims at horizontal integration, vertical integration and end-to-end integration. Moreover, IoT is a very complicated heterogeneous network, which includes the connection between various types of networks through various communication technologies [14]. Considering this scenario, some relevant future trends could be identified considering the technical aspects of manufacturing and assembly systems digitalisation:

- Standardisation

In this context, a first element of research is the standardisation. Global level of effort is required to develop a standardisation process to ensure successful implementation of the strategic vision of I4.0. RAMI4.0 (Reference Architecture Model I4.0) formalizes manufacturing resources as 'I4.0 components'. RAMI4.0 outlines a set of characteristics for a group of resources to be considered as I4.0 components, including identifiability, communication capability (e.g. via OPC-UA, Fieldbus, or TCP/IP), compliant services, states and semantics, virtual description, safety, security, quality of service, nestability, and separability [8]. Another effort of developing standardisation for I4.0 is the introduction of the Industrial Internet Reference Architecture (IIRA). IIRA is a standards-based open architecture defined by the Industrial Internet Consortium (IIC) [47]. The objective of IIRA is to create a capability to manage interoperability, map applicable technologies, and guide technology and standards development. At last, other standards like ISO-TC 184 [47] (within SC1, SC4, SC5) can be further implemented to guide the standardisation.

- Integration
  A second technical element is the integration of CPS. The integration of CPS includes integrating heterogeneous components, methods and tools. This challenge includes designing interfaces to support heterogeneous components and the adaptive integration of components. More research should be done to investigate the integration of cyber and physical systems. This type of integration will result in complexities from the interactions amongst cyber systems and the uncertain dynamic behaviour of physical systems.
- Service-orientated architecture (SOA)
  According to [8], the next generation enterprise architecture will be a service-oriented architecture (SOA) model adapted for manufacturing adoption. Service orientation will enable end-to-end and real-time value network coordination and enhance local autonomy and self-reconfigurability in the operative level.
- Smart devices
  A further technical element of future digital production system is the smart devices. An I4.0 manufacturing environment is intelligent which requires more advanced smart digital devices [48]. Smart objects will become more intelligent and context aware with larger memory, processing and reasoning capabilities. This will enable IoT systems with characteristics such as self-configuration, self-optimisation, self-protection and self-healing.
- New Industry 4.0 applications and technology transfer
  A set of potential application of I4.0 devices and manufacturing processes can be developed. A set of them could be designed as plug and play for different manufacturing application and industrial sectors [49]. The state of the art here is limited even if some contributes are present.

4.2 Organisational future trends

A set of organisational challenges offer potential future research areas for the new manufacturing and assembly system generation in the Industry 4.0 era distinguished by a remarkable production process digitalisation:

- Resilient smart factory
  A resilient smart factory would have systems that are tolerant to disruptions [10]. In I4.0, there are often high data flow rates and intensive processing requirements. As such, the system can experience insufficient system resources for processing to maintain high reliability. Smart factories are introduced to provide the reliability needed and are expected to be resilient. Although achieving resilience in I4.0 is challenging, efforts are needed to be directed to the interdisciplinary research that contributes to the development of a resilient industrial ecosystem.
- Employer skills evolutions
  All the past industrial revolutions did influence not only the production itself but also the labour market and the educational system as well [50]. The skills needed by employers in the I4.0 changed due to the evolution of the adopted technologies. A set of non-technical skills (communication, teamwork, innovation, creativity, critical thinking, problem-solving, self-entrepreneurship, computer programming, etc.) are required [50]. Universities and companies shall review the formative activities, research and valuable industrial training to meet current demands of the industrial evolving environment.
- Employers working activities
  The era of I4.0 will affect the style of work, transforming the traditional work-as-survival to work-for-life, to a final life-as-work. Moreover, in the positive trend of lengthening of working life, this effect could change the normal working pattern. It will free up more time for people to pursue their interests, which in turn enables more diverse and flexible career paths and will allow people to keep working and remain productive longer [51].

As shown in Fig. 3 for illustrating the design and management methodology of digital manufacturing and assembly systems in the Industry 4.0 era, the high-level Industry 4.0 design principles are followed by the Reference Architecture Model I4.0 (RAMI4.0), and then by the low-level Implementation of Manufacturing/Assembly Systems. That is to say, this methodology starts at the high-level design principles that are abstracted from RAMI4.0, which is in turn abstracted from the specific implemented manufacturing/assembly systems, which will be discussed in Section 5. Sections 3 and 4 have addressed the challenges faced by manufacturing and assembly systems in the Industry 4.0, and Section 2 addressed the enabling technologies.

The presented literature review shows that researchers worked in defining the new manufacturing and assembly paradigms in the I4.0 era, defining its implementation conditions and technologies along with future research agenda as consequence of a new developing digital production system. On the other hand, scientific research lacks of contributes describing novel automation technologies, ICT infrastructures, control algorithms, optimization models or industrial case studies for the new generation of digital manufacturing and assembly systems which distinguish I4.0 era. This special issue aims to contribute to this field of research proposing a set of selected researches focused on these topics.

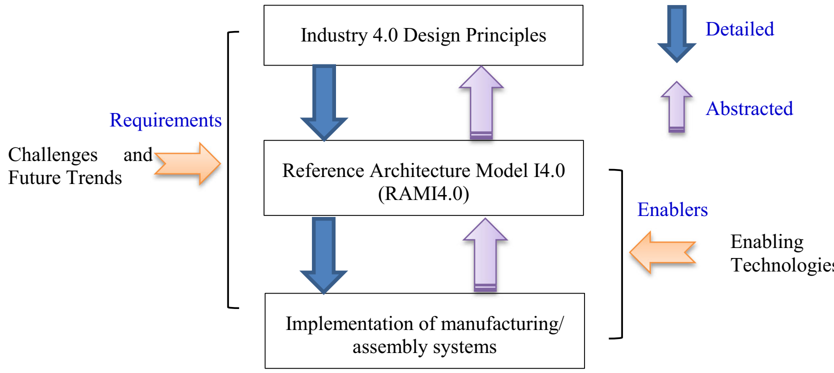

Fig. 3 Design and management of digital manufacturing and assembly systems in the Industry 4.0 era

5 Editorial overview of this special issue papers and their contributions

Twenty-six high-quality papers were selected for publication in this special issue from over 100 submissions. The research presented in these papers covers a variety of research topics: artificial intelligence for manufacturing processes, smart assembly station design and management, big data analytics for reconfigurable manufacturing systems, self-optimization models for assembly line balancing and sequencing, self-diagnosis methods based on IoT technologies, predictive maintenance and condition monitoring of machining tools, additive manufacturing technologies for on-demand production of personalized goods, AR technologies for operator assistance, innovative automation and robotic technologies to enhance the human-robot co-working, etc.

The papers were submitted from across Europe, America, Asia, Africa and Oceania. The reported research shows strong collaboration with several papers having joint authoring teams from different institutions or countries in different continents. In this Section, contributions from the selected papers will be briefly discussed.

Abidi et al. [52] extends VR applications in manufacturing by integrating concepts and studies from training simulations, to the evaluation of assembly training effectiveness and transfer of training. A series of user-based evaluation studies are conducted to ensure that the virtual manufacturing assembly simulation provides an effective and efficient means for evaluating assembly operations and for training assembly personnel.

Salazar et al. [53] provide a description and comparison of Multi-Agent Systems design patterns, which were collected and classified by introducing two classification criteria to support Multi-Agent Systems developers. A cyber physical production system architecture is proposed to fulfil the requirements related to the era of smart factories, as the Reference Architectural Model I4.0.

Kalami and Urbanic [54] propose a methodology to fabricate low volume production moulds using a high-temperature moulding material. A general solution is provided with a case study focusing on an over-moulding process in which the injection material being moulded is Technomelt-PA 7846 black. The authors apply a hybrid mould fabrication where a material extrusion-based process is used to make a sacrificial product-shaped pattern.

Stocker et al. [55] outlines a method which modifies this conventional process using reinforcement learning to automate the vibratory bowl feeders design. To enable this, a software agent is used to model the placement of traps on multiple positions and measure the subsequent configuration efficiency. A physics simulation provides the characteristics of the individual traps.

Cherubini et al. [56] introduces BAZAR, a collaborative robot that integrates the most advanced sensing and actuating devices in a unique system designed for the Industry 4.0. The authors present BAZAR's three main features, which are all paramount in the factory of the future. These features are as follows: mobility for navigating in dynamic environments, interaction for operating side-by-side with human workers and dual arm manipulation for transporting and assembling bulky objects.

Jayasekera and Xu [57] present an assembly validation system that is independent of CAD packages, interoperable and implemented using relatively low-cost and commercially available hardware and software tools. The system features intuitive bare-hand manipulation of part models through a virtual hand model that tracks the hands. Collision detection and physics modelling allow for hand-part and part-part interactions to be natural, thus validating assembly interactions.

Yacob et al. [58] propose the concept of Skin Model Shapes as a method to generate digital twins of manufactured parts as a new paradigm in the design and manufacturing industry. Skin Model Shapes use discrete surface representation schemes to represent surfaces, accurate tolerance analysis and surface inspection. To detect the unfamiliar changes, as anomalies, and categorize them as systematic and random variations, some unique surface characteristics can be extracted and studied leveraging machine learning classifiers.

Zheng et al. [59] propose a complete spreader fault tree with three layers of fault phenomena, fault classification and fault causes based on the historical fault data of the spreader, which is part of a crane used on wharfs for loading and unloading operations. Then, based on the fault tree, a Bayesian network for the spreader fault diagnosis is constructed by establishing the transformation algorithm from the fault tree to the Bayesian network.

Huang et al. [60] propose techniques for support detection in 3D printing to overcome the difficulties of image-based methods by a Surfel convolutional neural network–based approach. In this method, the sampling point on the surface with normal information is defined through layered depth-normal image sampling method. A local Surfel image which represents the local topology information of the sampling point in the solid model is then constructed.

Shafae et al. [61] propose a cyber-defence strategy that increases the difficulty/cost required for a successful attack on a manufacturing system. This strategy adapts quality control tools to act as physical detection layers to reach this goal—a machining-specific attack design scheme and an attack design designation system are proposed to provide the structure to populate a wide variety of potential attacks to manufacturing systems.

Rossit et al. [62] focus on manufacturing tools able to make decisions online and negotiate with the customer the changes that can be carried out according to the workload flowing through the production system. The ability of resequencing the production process is also implemented in the case that the operations associated with late customization allow it.

Li et al. [63] introduce the dynamic order acceptance and scheduling problem in on-demand production with powder bed fusion systems and aim to provide an approach for manufacturers to make decisions simultaneously on the acceptance and scheduling of dynamic incoming orders to maximize the average profit-per-unit-time during the whole makespan.

Zeller et al. [64] aim to assist production line operators in the validation process of their automation systems after software changes. A model-based technique is suggested to automate this creation process. By means of this, the subsystem affected by the software change is automatically identified and subsequently a suitable input to a model-based verification tool is generated.

Papanastasiou et al. [65] discuss the challenges in the collaboration between human operators and industrial robots for assembly operations focusing on safety and simplified interaction involving perception technologies for the robot in conjunction with wearable devices used by the operators. A robot manual guidance module and a vision system for recognition and tracking of objects are integrated with human wearable devices accompanied by augmented reality technology to support the operators in terms of production and safety aspects.

Sanderson et al. [66] present a Function-Behaviour-Structure methodology for Evolvable Assembly Systems, a class of self-adaptive reconfigurable production systems, comprising an ontology model and design process. This model is used as the input to a functional modelling design process for such assembly systems, where the design process must be integrated into the system control behaviour.

Zhang et al. [67] present an intelligent configuration method based on smart composite jig model to lower the requirement for designers' skills and enhance the agile joint jig design efficiency. Based on the above model, the intelligent configuration method for agile joint jig is proposed and realized by combing auto-selection reasoning with auto-assembly reasoning.

Antomarioni et al. [68] propose an innovative maintenance policy aimed at both predicting components breakages through association rule mining and determining the optimal set of components to repair in order to improve the overall plant's reliability, under time and budget constraints. An experimental campaign is carried out on a real-life case study concerning an oil refinery plant.

Gavidel et al. [69] present a statistical performance comparison methodology based on bootstrapping and hypothesis testing techniques to systematically compare the prediction performance of predictive models and determine the efficient models. Also, a deep neural net (DNN) nugget width prediction model is developed, analysed and compared with prior models.

Shoval and Efatmaneshnik [70] focus on the reliability and precisions that the use of cyber-physical systems such as robotics and automation in assembly processes has introduced. Considering the increasing complexity determined by such a system, a probabilistic process characterization model is proposed for smart assembly planning purposes.

Klumpp et al. [71] offer an interdisciplinary research perspective dealing with the future challenges for successful automated systems that rely mainly on human-computer interaction in connection with an efficient collaboration between motivated workers, automated robotics and transportation systems. A human-computer interaction efficiency description is developed in production logistics based on an interdisciplinary analysis.

Mezgebe et al. [72] propose a consensus algorithm for multi-agent-based manufacturing system to control the rush order and henceforth minimize a makespan of Cyber Physical System. Consensus is an algorithmic procedure applied in control theory which allows convergence of state between locally autonomous agents collaborating for their common goal.

Far et al. [73] propose a bi-objective flexible cell scheduling problem under time-of-use electricity tariffs in both deterministic and fuzzy environments with two objectives: total cost of production system and total delivery tardiness of jobs. To create a form of green and energy-conscious strategy, cost of produced emission and consumed power and some limitations are respected. Besides, a self-adaptive two-phase sub-population genetic algorithm is taken to find a near-optimum solution of suggested bi-objective fuzzy mixed integer linear programming model.

Remeseiro et al. [74] present a methodology to automatically detect defective crankshafts, which is a mechanical component of an engine, critical and very expensive. The proposed procedure is based on digital image analysis techniques, to extract a set of representative features from crankshaft images. Statistical techniques for supervised classification are used to classify the images into defective or not.

6 Concluding remarks

Through the research presented in this special issue, a series of challenges in digital manufacturing and assembly systems have been targeted and valuable contributions to both theory and application in this area have been achieved. In this editorial, existing and future challenges in research and applications on digital manufacturing and assembly systems in relationships with other important production process problems and issues have been discussed in detail. We believe that this special issue presents leading and relevant current research in the area of manufacturing and assembly systems in the I4.0 era that will be of interest for readers of the *International Journal of Advanced Manufacturing Technology* and provides a useful reference for future research.

Acknowledgement We would like, in particular, to acknowledge the contributions of the Journal Editor-in-Chief, Professor Andrew Y. C. Nee, to the special issue. He provided significant technical and administrative support during the editing and review process, and helped in assessing the quality and contributions of the manuscripts that were submitted for possible publication in the special issue.

References

1. Stankovic JA (2014) Research directions for the internet of things. IEEE Internet Things J 1(1):3–9
2. Bortolini M, Faccio M, Gamberi M, Pilati F (2017) Multi-objective assembly line balancing considering component picking and ergonomic risk. Comput Ind Eng 112:348–367
3. Nee AYC, Ong SK, Chryssolouris G, Mourtzis D (2012) Augmented reality applications in design and manufacturing. CIRP Ann Manuf Technol 61(2):657–679
4. Davies, R. (2015). Industry 4.0 Digitalisation for productivity and growth. European Parliamentary Research Service, 1.
5. Yao X, Lin Y (2016) Emerging manufacturing paradigm shifts for the incoming industrial revolution. Int J Adv Manuf Technol 85(5): 1665–1676. https://doi.org/10.1007/s00170-015-8076-0
6. Koren Y, Shpitalni M (2010) Design of reconfigurable manufacturing systems. J Manuf Syst 29(4):130–141
7. Bortolini M, Ferrari E, Gamberi M, Pilati F, Faccio M (2017) Assembly system design in the Industry 4.0 era: a general framework. IFAC-PapersOnLine 50(1):5700–5705
8. Moghaddam M, Cadavid MN, Kenley CR, Deshmukh A (2018) Reference architectures for smart manufacturing: a critical review. J Manuf Syst 49:215–225
9. Azzi A, Battini D, Faccio M, Persona A (2012) Sequencing procedure for balancing the workloads variations in case of mixed model assembly system with multiple secondary feeder lines. Int J Prod Res 50(21):6081–6098
10. GTAI (Germany Trade & Invest) (2014) Industries 4.0-smart manufacturing for the future. GTAI, Berlin
11. NIST (2017) Smart manufacturing operations planning and control program. National Institute of Standards and Technology, Gaithersburg 2017
12. Birtel, M., Mohr, F., Hermann, J., Bertram, P., & Ruskowski, M. (2018). Requirements for a humancentered condition monitoring in modular production environments. IFAC-PapersOnLine, 51(11), 909-914.
13. Rüßmann M, Lorenz M, Gerbert P, Waldner M, Justus J, Engel P, Harnisch M (2015) Industry 4.0: The future of productivity and growth in manufacturing industries. Boston Consulting Group, Boston
14. Ghobakhloo M (2018) The future of manufacturing industry: a strategic roadmap toward Industry 4.0. J Manuf Technol Manag 29(6):910–936
15. Manavalan E, Jayakrishna K (2019) A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements. Comput Ind Eng 127:925–953
16. Ashton K (2009) That 'Internet of Things' Thing. RFiD Journal 22: 97–114
17. Xu LD, He W, Li S (2014) Internet of Things in industries: a survey. IEEE T Ind Inform 10(4):2233–2243
18. Gudmundsson D, Goldberg K (2007) Optimizing robotic part feeder throughput with queueing theory. Assem Autom 27(2):134–140
19. Rosati G, Faccio M, Carli A, Rossi A (2013) Fully flexible assembly systems (F-FAS): a new concept in flexible automation. Assem Autom 33(1):8–21
20. Rosati G, Faccio M, Finetto C, Carli A (2013) Modelling and optimization of fully flexible assembly systems (F-FAS). Assem Autom 33(2):165–174
21. Bortolini M, Faccio M, Gamberi M, Pilati F (2018) Motion Analysis System (MAS) for production and ergonomics assessment in the manufacturing processes. Comput Ind Eng. https://doi.org/10.1016/j.cie.2018.10.046
22. Faccio M, Ferrari E, Gamberi M, Pilati F (2019) Human Factor Analyser for work measurement of manual manufacturing and assembly processes. Int J Adv Manuf Technol 103:861–877. https://doi.org/10.1007/s00170-019-03570-z
23. Xu B, Xu LD, Cai H, Xie C, Hu J, Bu F (2014) Ubiquitous data accessing method in IoT-based information system for emergency medical services. IEEE T Ind Inform 10(2):1578–1586
24. Mitra A, Kundu A, Chattopadhyay M, Chattopadhyay S (2017) A cost-efficient one time password-based authentication in cloud environment using equal length cellular automata. J Ind Inf Integr 5: 17–25
25. Moghaddam M, Nof SY (2018) Collaborative service-component integration in cloud manufacturing. Int J Prod Res 56:677–691
26. Chen H (2017) Theoretical foundations for cyber physical systems - a literature review. Journal of Industrial Integration and Management 2(3):1750013. https://doi.org/10.1142/S2424862217500130
27. NSF (2017) Cyber-physical Systems (CPS). https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503286.
28. Weber A (2016) Industry 4.0: myths vs. reality. Assembly 11:28–37
29. Heineke J, Davis MM (2007) The emergence of service operations management as an academic discipline. J Oper Manag 25(2):364–374

30. Yin Y, Stecke KE, Li D (2018) The evolution of production systems from Industry 2.0 through Industry 4.0. Int J Prod Res 56:848–861
31. Cohen Y, Faccio M, Galizia FG, Mora C, Pilati F (2017) Assembly system configuration through Industry 4.0 principles: the expected change in the actual paradigms. IFAC-PapersOnLine 50(1):14958–14963
32. Zhuang C, Liu J, Xiong H (2018) Digital twin-based smart production management and control framework for the complex product assembly shop-floor. Int J Adv Manuf Technol 96:1149–1163
33. Hanson R, Falkenstrom W, Miettinen M (2017) Augmented reality as a means of conveying picking information in kit preparation for mixed-model assembly. Comput Ind Eng 113:570–575
34. Oberc H, Prinz C, Glogowski P, Lemmerz K, Kuhlenkotter B (2019) Human Robot Interaction – learning how to integrate collaborative robots into manual assembly lines. Procedia Manufacturing 31:26–31
35. Yao F, Keller A, Ahmad M, Ahmad B, Harrison R, Colombo AW (2018) Optimizing the scheduling of autonomous guided vehicle in a manufacturing process. In: international conference on industrial informatics:264–269
36. Jantsch A, Dutt ND, Rahmani AM (2017) Self-awareness in systems on chip— a survey. IEEE Design & Test of Computers 34(6): 8–26
37. 3D HUBS (2019) CNC machining: The complete engineering guide. https://www.3dhubs.com/guides/cnc-machining/#basics.
38. Zhou J, Yao X, Liu M, Zhang J, Tao T (2017) A state-of-the-art review on new emerging intelligent manufacturing paradigms. Comput Integr Manuf Syst 23(3):624–639
39. Yao X, Zhou J, Zhang J, Boer CR (2017) From intelligent manufacturing to smart manufacturing for Industry 4.0 driven by next generation artificial intelligence and further on. In: International Conference on Enterprise Systems:311–318
40. Yao X, Zhou J, Lin Y, Li Y, Yu H, Liu Y (2017) Smart manufacturing based on cyber-physical systems and beyond. J Intell Manuf. https://doi.org/10.1007/s10845-017-1384-5
41. Jing X, Yao X (2019) Towards social cyber-physical production systems. Acta Automat Sin 45(4):637–656
42. Yao X, Jin H, Zhang J (2015) Towards a wisdom manufacturing vision. Int J Comput Integr Manuf 28(12):1291–1312. https://doi.org/10.1080/0951192x.2014.972462
43. Yao X-F, Lian Z-T, Yang Y, Zhang Y, Jin H (2014) Wisdom manufacturing: new humans-computers-things collaborative manufacturing model. Comput Integr Manuf Syst 20(6):1490–1498. https://doi.org/10.13196/j.cims.2014.06.yaoxifan.1490.9.20140627
44. Yao X, Zhang J, Lin Y (2016) The basic theory and technical framework for wisdom manufacturing systems. Systems Engineering - Theory & Practice 36(10):2699–2711
45. Yao X, Zhou J, Zhang C, Liu M (2017) Proactive manufacturing - a big-data driven emerging manufacturing paradigm. Comput Integr Manuf Syst 23(1):172–185
46. Yao X, Lei Y, Ge D, Ye J (2019) On big data that drives manufacturing from "Internet Plus" to "AI Plus". China Mechanical Engineering 30(2):134–142
47. Industrial Internet Consortium (2017) The industrial internet of things volume G1: reference architecture (Version 1.80)
48. Zhou K, Liu T, Zhou L (2015) Industry 4.0: Towards future industrial opportunities and challenges. In: fuzzy systems and knowledge discovery:2147–2152
49. Cohen Y, Golan M, Singer G, Faccio M (2018) Workstation-Operator Interaction in 4 0 Era: WOI 4 0. IFAC-PapersOnLine 51(11):399–404
50. Azmi AN, Kamin Y, Noordin MK, Nasir MAN (2018) Towards industrial evolution 4.0: employers' expectations on fresh engineering graduates. International Journal of Engineering and Technology(UAE) 7(4):267–272
51. Branger J, Pang Z (2015) From automated home to sustainable, healthy and manufacturing home: a new story enabled by the Internet-of-Things and Industry 4.0. Journal of Management Analytics 2(4):314–332
52. Abidi MH, Al-Ahmari A, Ahmad A, Ameen W, Alkhalefah H (2019) Assessment of virtual reality-based manufacturing assembly training system. Int J Adv Manuf Technol:1–17. https://doi.org/10.1007/s00170-019-03801-3
53. Salazar LAC, Ryashentseva D, LüderA, Vogel-Heuser B (2019) Cyber-physical production systems architecture based on multi-agent's design pattern–comparison of selected approaches mapping four agent patterns. The International Journal of Advanced Manufacturing Technology.
54. Kalami H, Urbanic RJ (2019) Design and fabrication of a low-volume, high-temperature injection mould leveraging a 'rapid tooling'approach. Int J Adv Manuf Technol:1–17. https://doi.org/10.1007/s00170-019-03799-8
55. Stocker C, Schmid M, Reinhart G (2019) Reinforcement learning–based design of orienting devices for vibratory bowl feeders. Int J Adv Manuf Technol:1–12. https://doi.org/10.1007/s00170-019-03798-9
56. Cherubini A, Passama R, Navarro B, Sorour M, Khelloufi A, Mazhar O et al (2019) A collaborative robot for the factory of the future: BAZAR. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03806-y
57. Jayasekera RDMD, Xu X (2019) Assembly validation in virtual reality—a demonstrative case. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03795-y
58. Yacob F, Semere D, Nordgren E (2019) Anomaly detection in Skin Model Shapes using machine learning classifiers. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03794-z
59. Zheng Y, Zhao F, Wang Z (2019) Fault diagnosis system of bridge crane equipment based on fault tree and Bayesian network. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03793-0
60. Huang J, Kwok TH, Zhou C, Xu W (2019) Surfel convolutional neural network for support detection in additive manufacturing. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03792-1
61. Shafae MS, Wells LJ, Purdy GT (2019) Defending against product-oriented cyber-physical attacks on machining systems. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03805-z
62. Rossit DA, Tohmé F, Frutos M (2019) An Industry 4.0 approach to assembly line resequencing. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03804-0
63. Li Q, Zhang D, Wang S, Kucukkoc I (2019) A dynamic order acceptance and scheduling approach for additive manufacturing on-demand production. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03796-x
64. Zeller, A., Jazdi, N., & Weyrich, M. (2019). Functional verification of distributed automation systems. The International Journal of Advanced Manufacturing Technology, 1-14. https://doi.org/10.1007/s00170-019-03791-2
65. Papanastasiou S, Kousi N, Karagiannis P, Gkournelos C, Papavasileiou A, Dimoulas K, Baris K, Koukas S, Michalos G, Makris S (2019) Towards seamless human robot collaboration: integrating multimodal interaction. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03790-3
66. Sanderson D, Chaplin JC, Ratchev S (2019) A Function-Behaviour-Structure design methodology for adaptive production systems. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03823-x
67. Zhang, H., Zheng, L., Wang, P., & Fan, W. (2019). Intelligent configuring for agile joint jig based on smart composite jig model. The International Journal of Advanced Manufacturing Technology, 1-23. https://doi.org/10.1007/s00170-019-03803-1

68. Antomarioni S, Pisacane O, Potena D, Bevilacqua M, Ciarapica FE, Diamantini C (2019) A predictive association rule-based maintenance policy to minimize the probability of breakages: application to an oil refinery. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03822-y
69. Gavidel, S. Z., Lu, S., & Rickli, J. L. (2019). Performance analysis and comparison of machine learning algorithms for predicting nugget width of resistance spot welding joints. The International Journal of Advanced Manufacturing Technology, 1-18. https://doi.org/10.1007/s00170-019-03821-z
70. Shoval S, Efatmaneshnik M (2019) Managing complexity of assembly with modularity: a cost and benefit analysis. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03802-2
71. Klumpp M, Hesenius M, Meyer O, Ruiner C, Gruhn V (2019) Production logistics and human-computer interaction—state-of-the-art, challenges and requirements for the future. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03785-0
72. Mezgebe TT, Demesure G, El Haouzi HB, Pannequin R, Thomas A (2019) CoMM: a consensus algorithm for multi-agent-based manufacturing system to deal with perturbation. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03820-0
73. Far MH, Haleh H, Saghaei A (2019) A fuzzy bi-objective flexible cell scheduling optimization model under green and energy-efficient strategy using Pareto-based algorithms: SATPSPGA, SANRGA, and NSGA-II. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03797-w
74. Remeseiro B, Tarrío-Saavedra J, Francisco-Fernández M, Penedo MG, Naya S, Cao R (2019) Automatic detection of defective crankshafts by image analysis and supervised classification. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-019-03819-7

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.