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Service Oriented, Holonic and Multi-Agent Manufacturing Systems for Industry of the Future

Proceedings of SOHOMA 2020

Springer

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Foreword

I would like to thank the SOHOMA Steering Committee for offering me the opportunity to share my views and ideas with the SOHOMA community and the manufacturing control and systems domain researchers at large. I worked in manufacturing control for more than twenty years and have witnessed the research progress of the domain from the first distributed architectures, including first holonic manufacturing systems models, to the myriad models for digital transformation of manufacturing through service orientation, and to the distributed intelligence models that are employed in what was recently called "manufacturing as a service" or shortly MaaS. The SOHOMA workshop, now at its anniversary tenth edition, has always kept with the times and even went through a few name changes to better capture the evolving nature of our work as a community. But, nevertheless, it always welcomed submissions from around the world covering cutting-edge manufacturing control modelling, promoted transformative research and moved forward the knowledge frontier. As confirmation, the last SOHOMA workshop held in October featured the overarching theme "manufacturing as a service—virtualizing and encapsulating manufacturing resources and controls into cloud networked services" and, to name a few, included articles covering MaaS aspects such as cloud-based manufacturing control, digital twins in manufacturing, holonic and multi-agent process control, ethics and social automation, human factors integration, and physical Internet and logistics.

This foreword makes an attempt to capture the readers' attention by highlighting current MaaS developments, as well as outline potential areas of research for the SOHOMA community and beyond. Manufacturing as a service includes local and potentially geographical distributed, service-oriented, knowledge-based smart manufacturing models that provide customized design and product solutions to individual or group-based customer types. It leverages technologies such as big data analytics, cloud, edge and fog computing, digital twins, artificial intelligence/machine learning (AI/ML), including deep learning, 3D printing, 5G broadband and SDN networks, and Internet of things. All within constraints such as high efficiency, safety of operations, cybersecurity of digital transactions, ethics, human–machine interaction, low energy consumption and reduced logistics imprint.

Including synergistic processes such as design as a service (DaaS), predict as a service (PraaS) and maintain as a service (MAaaS) results in bringing into being of a robust, responsive, secure, value chain-based and customer-oriented MaaS ecosystem that goes beyond the separate "smart factory" or digital manufacturing solutions. The quintessential research objective to accomplish this vision is to investigate the seamless integration of the above technologies into the MaaS ecosystem. SOHOMA researchers already started the heavy lifting for this daring task by building on the previous editions of the workshop and especially on the work presented at the current anniversary edition.

While I cannot address here all the above-named MaaS technologies and their constraint-based ecosystem integration, I will be making the case for the MaaS AI/ML-based control software and cybersecurity assessment for future manufacturing systems. In future, tailored MaaS computational software systems will be enabled by sensor-equipped resources, scalable data infrastructure, fast and reliable secure communications, cloud, edge and fog computing, real-time operating systems and predictive analytics. AI/ML adaptive control systems will increase the generality and scale of the search space and include remote possible combinations of inputs, controls and environmental conditions. Hence, AI/ML systems will be able to select among many feasible system responses, including some that otherwise might have been overlooked. Algorithm training will eliminate responses that do not provide the optimal control action and responses for which the control action is provided too late, too early, or out of sequence, or applied too long or stopped too soon. AI/ML systems will have provisions for outlier detection and work with sets of data having some or all of the known big data "V" characteristics: volume, variety, velocity, volatility, value and variability. The big step forward towards what is called artificial general intelligence (AGI) domain should not make a detour for manufacturing control and initial characteristics of AGI, such as the below, are expected to be implemented in the decades to come:

- Avoiding negative side effects: ensure adverse actions towards the actors and the environment are not introduced through objective function optimization.
- Avoiding reward hacking: ensure the cumulative reward is not maximized at the cost of exposing the system to attacks.
- Scalable oversight: ensure the objective function can be optimized when frequent evaluation of constraints may not be cost effective.
- Safe exploration: ensure the probabilistic activities taken to avoid local optimum solutions do not result in increased system vulnerabilities.
- Robustness to distributional shift: ensure no unsafe actions are performed in an environment having distinct characteristics than the training environment.

I am looking forward for SOHOMA researchers to delve into building MaaS AI/ML control software that addresses one or more of the above characteristics and in ten years, at the twentieth anniversary workshop, to report on their transformative AI/ML manufacturing research.

On the second topic I mentioned above, cybersecurity assessment for future manufacturing systems, there is so much to talk about which is both good and not so good. In contrast to other domains of the global economy, manufacturing was not the subject to sustained and successful cybersecurity attacks. It seems that manufacturing organizations do not necessarily consider themselves at risk for cybersecurity attacks. The discussion here does not cover the IT systems of manufacturing organizations, which carry the same risk as other IT domain systems, but rather the specific systems for manufacturing operations. The variety of cyber-physical systems, industrial control systems, supervisory control and data acquisition systems (SCADA), and networked machines, sensors, data and control software are all at risk, with the manufacturing supply chain being at an elevated risk. As it can be inferred, MaaS includes all these types of systems and additionally more. Bringing into being the MaaS ecosystem is not possible without strong cybersecurity measures in place. The probability of an unprecedented cyber-attack with serious implications in the manufacturing domain is increasing by the day, so preparation must start now.

I talked above about MaaS software control using AI/ML, but the fact is AI/ML systems can also be used in future for cybersecurity preparation. They can be used to test and prepare for worst-case scenarios and to analyse potential cyber-threats to the MaaS systems using sensor data and defensive systems responses. They can be used to enhance human–machine integration and minimize any human error consequences in the MaaS ecosystem. They can be used to discover patterns and anomalies in different customer or manufacturer datasets and thus assess the likelihood of an attack. Finally, they can be used to securely develop, deploy and operate MaaS software systems, and protect against low-level attack vectors or logic errors. Some of the potential research topics for SOHOMA researchers in the years to come include:

- Predictions related to potential attackers' intent against the MaaS ecosystem.
- Uncertainty planning for cooperative and non-cooperative environments, both being equally possible in the competitive MaaS ecosystem.
- Predictions related to human erroneous decisions that inadvertently increase MaaS system vulnerability.
- Verification and validation of datasets for identification of detrimental flaws and vulnerabilities that can be externally exploited.
- Implementation of best practices for secure system operations that reduce the internal threat in the MaaS ecosystem.

Cybersecurity protection of manufacturing environment is at crossroads and the only step forward is changing the mindset of it being an IT issue and make it an integral part of the MaaS ecosystem research. Again, I look forward for SOHOMA researchers to address the cybersecurity assessment of future manufacturing systems and report their work at the coming SOHOMA workshops.

I hope our readers will enjoy and find valuable the high-quality articles included in this anniversary volume. I am confident that previous SOHOMA authors will continue to contribute to the advancement of manufacturing research, and I invite other academia and industry practitioners reading this volume to submit their work to the future editions of the SOHOMA workshop. Together we will build the manufacturing systems for the industry of the future.

November 2020 Radu Babiceanu

Preface

This volume gathers the peer-reviewed papers presented at the tenth edition of the international workshop on Service Oriented, Holonic and Multi-Agent Manufacturing Systems for Industry of the Future—SOHOMA’20 organized on 1–2 October 2020 by Arts et Métiers ParisTech in collaboration with University Politehnica of Bucharest (the CIMR Research Centre in Computer Integrated Manufacturing and Robotics), Université Polytechnique Hauts-de-France (the LAMIH Laboratory of Industrial and Human Automation Control, Mechanical Engineering and Computer Science) and Polytechnic Institute of Bragança (the CeDRI Research Centre in Digitalization and Intelligent Robotics).

The main objective of SOHOMA workshops is to foster innovation in smart and sustainable manufacturing and logistics systems by promoting concepts, methods and solutions addressing trends in service orientation of agent-based control technologies with distributed intelligence.

The book is structured in eight parts that correspond to the technical sessions of the workshop’s program and include papers describing results of the research addressing the development and application of key enabling technologies (KET: production-, digital- and cyber-physical technologies) for the industry of the future. In concurrence with this vision of future manufacturing, the eight sections of the book address control and organization problems in the manufacturing value chain and offer smart solutions for smart factories networked in the cloud, implemented in cyber-physical systems with all resources integrated, sharing information and infrastructures, collaborating, adapting to reality and self-configuring at runtime for efficiency, agility and safety.

These subjects are treated in the book’s *Part 1*: Cloud Networked Models of Knowledge-based Intelligent Control; *Part 2*: Digital Twins in Manufacturing and Beyond; *Part 3*: Holonic and Multi-Agent Process Control; *Part 4*: Ethics and Social Automation in Industry 4.0; *Part 5*: New Organizations based on Human Factors Integration in Industry 4.0; *Part 6*: Intelligent Products and Smart Processes; *Part 7*: Physical Internet and Logistics; *Part 8*: Optimal Production and Supply Chain Planning.

Along the nine previous annual workshop editions, the SOHOMA scientific community introduced and developed new concepts, methods and solutions that aligned with the worldwide effort of modernizing and digitalizing manufacturing in the twenty-first century's context of high dynamics market globalization, product-centric control, direct digital manufacturing, customer- and service-oriented manufacturing, enterprise networking and cloud-based infrastructure sharing. The ten-year anniversary edition in 2020 hosted presentations of the most important research contributions of SOHOMA groups, which are also included in this book. These papers reflect continuity in approach and demonstrate the impact of the community's research reported on specific evolution lines in manufacturing systems towards 'industry of the future' (IoF).

SOHOMA research has identified and permanently addressed the *technological and computational enablers* that potentiate the IoF characteristics: global optimization and intelligence distribution in manufacturing execution systems (MES); decoupling supervision from control; extended digital modelling of processes, products and resources; pervasive instrumenting of shop floor entities and edge computing in the industrial Internet of things (IIoT) framework; strongly coupling systems of systems of autonomous and cooperative elements in cyber-physical systems (CPS) according to the holonic paradigm; on-demand sharing of technology and computing resources through cloud-type services; predictive production control and resource maintenance based on artificial intelligence (AI, machine learning-ML) techniques. Concerning these enablers, *orchestrating* technologies are essential to coordinate and synchronize the two classes of IoF enablers towards implementation and deployment. There are three such technologies that have been systematically developed, applied and improved during the last decade; they represent the triple brand of the SOHOMA scientific community: **service orientation**, **holonic manufacturing** and **multi-agent systems** (MAS) in the industrial environment.

Service orientation in the manufacturing domain was not limited to just Web services or technology and technical infrastructure either; instead, service-oriented architectures (SOA) which were developed reflect a new way of thinking about processes, resources, orders and their information counterparts (the service-oriented agents) reinforcing the value of commoditization, reuse, semantics and information, and creating business value for the factory. A complete manufacturing service (MService) theory and implementing model have been established.

The holonic paradigm has been used to develop smart, distributed manufacturing control architectures (for mixed batch planning and scheduling, resource allocation, material flow and environment conditioning), based on the definition of a set of abstract entities: resources (technology, humans—reflecting the producer's profile, capabilities, skills), orders (reflecting the business solutions) and products (reflecting the customers' needs, value propositions). These entities are represented by autonomous holons communicating and collaborating in holarchies to reach a common production-related goal. The holonic paradigm provides the attributes of flexibility, agility and optimality by means of a completely decentralized manufacturing control architecture based on a social organization of intelligent entities called holons with specific behaviours and goals. From the control perspective, in the dynamic organizations of holons (the holarchies), decision-making characteristics (e.g. scheduling, negotiating, allocating, reconfiguring) are combined with reality-reflecting features (robustness, fault-tolerance, agility) provided by holons. Holarchies allow for object-oriented aggregation, while the specialization incorporated in control architectures provides support for abstraction; in this way, the holonic control paradigm has been increasingly transposed in control models of diverse types of industrial processes.

The shop floor control scheme is scalable, decoupled from the decision-making (supervision) MES layer which assures adaptability and reconfigurability of the global production control which is thus keeping free of induced constraints and limitations such as myopia or the incapacity to react at unexpected events.

In the context of holonic manufacturing, the strongly coupled networks of software agents—information counterparts of holons' physical parts—cooperate to solve global production problems. These are multi-agent systems that constitute the implementing frameworks for holonic manufacturing control and reengineering of shop floor resource coalitions. MAS allow distributing intelligence in the MES. They are able to control in decentralized (heterarchical) mode production systems.

Mixed approaches were developed, e.g. patterns of delegate MAS (D-MAS) are mandated by the holons representing structural production elements to undertake tasks reconfiguring operation scheduling and resource allocation in case of disturbances such as resource breakdowns. Bio-inspired MAS for manufacturing control with social behaviour and short-term forecasting of resource availability through ant colony engineering or recurrent neural networks are AI-based techniques for heterarchical control with MAS.

Because reality awareness and robustness of control systems represent priorities of the industry, semi-heterarchical models of holonic manufacturing control were developed to offer a dual behaviour that combines optimized system scheduling with agile, reactive scheduling that is done in real time by D-MAS. The semi-heterarchical manufacturing control architecture deals rapidly with unexpected events affecting orders in current execution, while computing in parallel (eventually in the cloud) new optimized schedules for the rest of orders waiting to be processed; this operating mode reduces the myopia of the system at global batch level and preserves the system's agility.

In the SOHOMA research, MAS were often used as implementing framework for holonic semi-heterarchical control in SOA. The three orchestrating technologies represent the basis of manufacturing CPS design and implementing; book chapters in part 3 and part 8 describe research carried out in these three topics.

During the past ten years, a lot of research works have been done by the SOHOMA community in the domain of **intelligent products**. Intelligent products (IP) are created temporarily in the production stage by embedding intelligence on the physical order or product that is linked to information and rules governing the way it is intended to be made (with recipe, resources), routed, inspected and stored; this enables the product to support and/or influence these operations. IP virtualization moves the processing from the intelligence embedded in the product to the virtual machine in the cloud using a thin hypervisor on the product carrier and WI-FI connection, either in a dedicated workload or in a shared workload to make decisions relevant to its own destiny. The research contributions can be grouped in three areas: 1) product-driven systems, 2) product lifecycle information systems and 3) physical Internet.

Product-driven systems (PDS) were defined as a way to optimize the whole product lifecycle by dealing with products whose informational content is permanently bound to their virtual or material contents and are able thus to influence decisions made about them, participating actively to different control processes in which they are involved throughout their lifecycle. Designing a PDS is a challenge that involves three fundamentals aspects: functions, architecture and interactions. Several bio-inspired approaches have been proposed by SOHOMA authors such as ant colony optimization, the firefly algorithm and a mechanism inspired from stigmergy using the notion of volatile knowledge.

An important facet of the intelligent product is related to data. There have been defined two levels of product intelligence (PI): 1) Level 1 (information-oriented)—PI is related to the (customer) needs linked to the production order, e.g. goods required, quality, timing, cost agreed; PI allows communicating with the local organization (and with the customer for the order); PI monitors/tracks the progress of the order through the industrial supply chain; 2) Level 2 (decision-oriented)—PI influences the choice between different options affecting the order when such a choice needs to be made; PI adapts the order management depending on real production conditions. The management of product information along the product's lifecycle was treated in the community's research work by means of distributed *Product Lifecycle Information Management* (PLIM) Systems. Different PLIM architectures messaging protocols and formats have been proposed. The EPCIS architecture is one such distributed data management architecture, specially adapted to product tracking in the supply chain [32]. DIALOG is another architecture proposed by SOHOMA members, based on a multi-agent system distributed in every actor of a given supply chain. In this architecture, a specific messaging protocol initially called product messaging interface (PMI) and further named quantum lifecycle management (QLM) is used.

The *physical Internet* (PI) concept has been proposed and formally defined as an open global logistics system leveraging interconnected supply networks through a standard set of modular containers, collaborative protocols and interfaces for increased efficiency and sustainability. The concepts of physical Internet and intelligent product were merged in SOHOMA works with the main idea to realize the notion of PI-container (smart container used in the physical Internet paradigm) by applying the activeness concept to a normal container. Also, concepts from the PDS area have also been applied to the physical Internet, e.g. the PROSIS architecture was first applied in an intra-logistics context that uses wireless holon networks constituted by mobile holons (shuttles, moving products) and fixed holons (workstations).

Parts 6 and 7 of the book include descriptions of SOHOMA research in the areas of intelligent product and physical Internet.

Introduced first as the "Conceptual Ideal for Product Lifecycle Management" (PLM) centre, the **digital twin** concept was developed by the SOHOMA scientific community with all its currently accepted elements—real space, virtual space and connection with data/information flow between the virtual and real space. Within digital twin research at SOHOMA, a set of envisioned functions of DTs has been formulated: it was assumed that the primary function of DTs should be to reflect the reality of their physical counterpart as a single source of truth. This then represents the value of DTs, because the accurate and updated mirroring of reality is extremely valuable and plays a critical role in effective control, scheduling and planning. In order to perform this primary function, DT architectures and implementations must provide key supporting functions, such as:

- Support data and information exchange between physical and digital worlds.
- Gather and aggregate data from the physical world, from multiple sources.
- Couple the virtual representation to their physical counterpart.
- Store historical data of the physical twin over its entire lifespan

Building on these supporting functions, the reported research works frequently refer to the high-level functions, or roles, that DTs are envisioned to fulfil. These roles can be summarized as follows: remote monitoring, predictive maintenance, simulation of "what-if" scenarios, planning and optimization. Three regimes can be distinguished in the above four roles: Firstly, some roles require an *emulation* of the physical twin (i.e. remote monitoring that reflects the current operation). Secondly, some roles rely on a *simulation model* of the physical twin to predict its future behaviour, either using historical information (e.g. predictive maintenance) or a combination of historical information and chosen scenarios (e.g. planning and "what-if" simulations). The third regime, *control*, is also focused on the future but is aimed at affecting the physical twin's behaviour (e.g. planning and optimization). The simulation regime contains the roles that most significantly distinguish a DT from a supervisory control and data acquisition system.

The DT architectures developed by SOHOMA groups aim to encapsulate the functionality of the DT in multiple layers (usually six layers); this principle results from the holonic systems influence in DT design. At the lowest level of these architectures are the interfaces to the physical twin, where data is gathered through smart sensors, embedded devices, device controllers and data acquisition systems. The open platform communications unified architecture (OPC UA) is proposed for the transfer of the collected data to the cyber-levels of the architecture—in essence on layers 2 and 3 (data sources, data transmission, data stream processing—equivalent in their functionality). All DT architectures emphasize the need for data aggregation, aligning in time and map-reducing, as achieved in layer. This function aims to convert raw sensed data into contextualized information and to reduce the amount of (streamed) data that must be processed and analysed within the DT. Database storage for historical information is used to support the highest levels of functionality in DT architectures, referred either as 'analysis and decision-making' or 'machine learning'; these functions are inferred by providing decision-makers with access to emulation and simulation functions that build on the DT data.

It is considered that in future, digital twins will become middleware interfacing many applications in manufacturing systems, as well as reality models embedded in control that use not only currently measured data from processes, but also historical information about components, behaviours and events and forecasts of these data; this will assure accurate reality awareness, realistic optimization and prediction of unexpected events during the manufacturing cycle. However, the high variability of technologies and the large amount of data to be collected from shop floor devices and processed in real time tend to increase the complexity of software development which might become the main barriers to achieving actual DT implementations on industrial scales, unless big data streaming techniques and HPC analytics are made available for real-time contexts.

DT research contributions of SOHOMA authors and an historical overview are described in part 2 of this book.

Cloud manufacturing (CMfg) is a research topic constantly addressed by the scientific SOHOMA community in accordance with its general evolution and relationship with advances in information, communication and control technologies (IC^{2}T)—for all three KET domains—applied to the manufacturing industry. CMfg moved the vision of dynamic mass customization a step further by providing service-oriented networked product development models in which clients may configure, select and use customized product-making resources and services, ranging from computer-aided design and engineering software to reconfigurable manufacturing systems.

In early SOHOMA research stage (2010–2012), contributions related to CMfg addressed the vertical integration of manufacturing enterprises having already adopted cloud computing on the higher layers of business and operations management processes for supply, ERP and digital marketing, however not yet integrated with the production and logistics layers. The integration along the vertical enterprise axis: business management, ERP, high-level production control (MES), shop floor distributed control is based on the SOA concept and marks a shift from the agent-centric architecture to SOA. The application of SOA principles in the factory automation domain consisted in encapsulating the functionality and business logic of components in the production environment (legacy software and devices) by means of Web services. Cloud-based enterprise networking in the manufacturing value chain (MVC) was also part of the 'enterprise integration' theme in this early CMfg research stage.

The design of cloud models and infrastructures for manufacturing was an objective of the SOHOMA scientific community, who considered that cloud services for MES are based on the virtualization of shop floor devices and a new control and computing mode that operates in the global cloud manufacturing model (CC-CMfg), with progressive solutions towards real time. In the vision of the SOHOMA community, CC-CMfg services orchestrate a dual OT (operation technology control) and IT (computing) model that:

[1] Transposes pools of shop floor resources (robots, CNC machines), products (recipes, client spec.), orders (work plans, task sequences) into *on-demand* making services;
[2] Enables pervasive, on-demand network access to a shared pool of configurable HPC resources (servers, storage, applications) that can be rapidly provisioned and released as services to various high-level MES tasks with minimal management effort or interaction. Hence, CC-CMfg may use cloud computing facilities.

There were proposed CC models (public + private) and techniques for the integration of an infrastructure-as-a-service (IaaS) cloud system with a manufacturing system based on the virtualization of multiple shop floor resources (robots, machines). Major contributions were brought for the virtualization of shop floor entities (resource, intelligent product) and MES workloads in the cloud. The solutions use a combination of virtual machines (VM) deployed in cloud before production start (offering the static part of services) and of containers executed on the VMs which run the dynamic part of services because they are deployed much faster than VMs. High availability (HA) methods and software-defined networking (SDN) mechanisms for interoperability, resilience and cybersecurity in dual CC-CMfg architecture were also developed being considered as major achievements.

The full dual CC-CMfg model was adopted for production planning and control of manufacturing systems with multiple resources and products with embedded intelligence. CC features were taken over by operational technologies (control, supervision, dynamic reconfiguring): i) the product-making services are provisioned automatically by MES optimal resource allocation programs; ii) the CC component offers network access to HPC services through distributed message platforms such as the manufacturing service bus (MSB); iii) the shop floor resources are placed in clusters with known location relative to the material flow and dynamically assigned at batch run time; this location is one input parameter weighting the optimal resource allocation; iv) the CC services can scale rapidly in order to sustain the variable real-time computing demand for order rescheduling respectively anomaly detection, the resources being assigned or released elastically; v) the assigned CMfg resources are monitored and controlled and both the MES (service consumer) and the cloud (service provider) are notified about the usage within the smart control application; the cost model '*pay as you go*' is used to establish the cost offers for client orders in service-level agreements. Such cloud models and services were developed for optimized, energy-aware production at batch level with resource sharing in semi-heterarchical control topology.

The SOHOMA community worked out ML-based approaches for reality awareness and efficiency in cloud manufacturing and proposed applications of machine learning algorithms for global optimization of manufacturing at batch level, robust behaviour at disturbances and safe utilization of manufacturing resources. The focus was put on the prediction of key performance indicators (KPI) like instant power consumption of resources, energy consumption and/or execution time for product operations, to provide more accurate input for the cloud-based system scheduler (SS)—optimization engine for mixed product and operation scheduling plus resource allocation: in addition to history (stored records) or current (last measured) energy consumption values, short-term forecasted values are used as input for SS optimization at batch execution horizon. Three new technologies were used for this type of smart cloud-based manufacturing control:

- Big data (BD) streaming for shop floor data processing: aggregating at the right logical levels when data originates from multiple sources; aligning data streams in normalized time intervals; extracting insights from real-time data streams.
- Digital twins (DT) of production assets (resources, products and orders) and system actions (control, maintenance and tracking) to record and maintain a complete view of past behaviours and KPIs of resources, processes and outcomes, and to forecast their future evolutions. Recording historical data is needed to train ML patterns.
- ML workload virtualization in cloud using HPC and fast deployment techniques for: i) *updating DTs*: deep learning patterns and measurement variations as basis for predictions; classification, when DT finds classes for feature vectors; clustering, which searches and identifies similarities in non-tagged, multiple-dimension data and tags suitably each feature vector; ii) *embedding DTs*: making intelligent decisions for smart production control in two roles: smooth reconfiguring of CMfg resources for global batch optimization based on the predicted cost of their usage; resource health management and predictive maintenance.

The SOHOMA research focuses on the use of AI methods in the cloud-based smart manufacturing control vision of the ‘factory of the future’ (FoF), based on the concepts of digitalization and interconnection of distributed manufacturing entities in a ‘system of systems’ approach: i) new types of production resources are strongly coupled and self-organizing in the entire value chain while products will decide upon their own making systems; ii) new types of decision-making support will be available from real-time production data collected from resources and products.

The vision on the future of cloud manufacturing research relies on the concept of ‘cloud anything’ extended beyond the production phases and facilities. This vision integrates the technologies and tools available for industry such as: PLM, PLC, MES, ERP and the frameworks under development (CPS for production and industrial IoT-IIoT) with the dual cloud model CC-CMfg on top of these infrastructures to create a product–service-centric closed-loop collaboration.

From the product lifecycle perspective, both the virtual (*design and engineering*) and the physical parts of the product (*making*) are assisted respectively tracked in the cloud. In fact, products conceived and designed to be embedded with intelligence and so to be “smart” both in production (*product-driven automation*) and utilization phases (*after sales*) are able to exchange information both within and beyond the limit of the factory. These smart objects are connected in the cloud with assets and enterprises in the supply networks and can provide a new type of cooperation, enabling collaborative demand and supply planning, traceability and execution.

Part 1 of the book includes papers describing research results in CMfg.

Research at SOHOMA also considers a **human-centred approach** to the design of intelligent manufacturing systems pointing out that modern manufacturing systems must have human awareness in the IoF vision, while keeping human decision-making in the loop at different levels of automation. The research is focused on the integration of human factors in system design, the optimization of human resource organization, improving working conditions, reducing musculoskeletal disorders risks, etc. Considering the integration of humans into Industry 4.0 environments, the operators' roles become more dynamic and decision-oriented. Operators in factories of the future require freedom from laborious tasks, flexibility in communication, and personalized and optimized information delivery.

Research works proposed ambient intelligence environments which are comprised of intelligent interfaces supported by embedded computing and networking technology; such architectures manage human–machine communication through available interfacing services as part of a digital administration shell for integrating human workers into the Industry 4.0 environment. For autonomous cyber-physical systems as future production systems, a variety of technologies and mechanisms integrating humans and machines have been analysed, among which benchmarking platforms.

Based on the development of artificial intelligence models and methods, Industry 4.0 fosters the development of more autonomous, intelligent systems interacting or cooperating with humans; SOHOMA authors consider that these developments should pay strong attention to ethical and societal issues involved in the design, development, operation and maintenance of such systems and their automation beyond classical key performances indicators expressed in terms of effectiveness or efficiency. **Ethics and social automation** must get the necessary and sufficient consideration with the emergence of autonomous intelligent systems (AIS) not only in controlled environments but in society at large and with tangible applications that affect people.

Aspects relevant to ethics of the artificial and social automation have been addressed by SOHOMA groups: ethical behaviour of researchers (ethical design of systems, techno-ethics), the study of the ethical behaviour of artificial systems designed (design of ethical systems, machine ethics), the impact of automation on society, the ethical risks relevant to the over-integration of humans with artificial systems (e.g. operator 4.0), algorithmic bias and transparency in autonomous intelligent systems and their applications. Interdisciplinary research on AIS and studies on the applicability of different ethical and societal frameworks in Industry 4.0 including legal and economic aspects have been also undertaken with complementary analyses from philosophy, sci-fi literature and other fields relevant to humanities.

The theme of the SOHOMA'20 workshop is 'manufacturing as a service—virtualizing and encapsulating manufacturing resources and controls into cloud networked services'.

Manufacturing as a service or shortly MaaS stands for new models of service-oriented, knowledge-based smart manufacturing systems optimized and reality-aware, with high efficiency and low energy consumption that deliver value to customer and manufacturer via big data analytics, edge computing and industrial IoT communications, cognitive robotics, digital twins and machine learning—components of cyber-physical systems. From product design to after-sales services, MaaS relies on the servitization of manufacturing operations that can be integrated into different manufacturing cloud service models, such as design as a service (DaaS), predict as a service (PraaS) or maintain as a service (MNaaS).

MaaS relies on a layered cloud networked manufacturing perspective, from the factory low-level CMfg shop floor resource sharing model to the virtual enterprise high-level, by distributing the cost of manufacturing infrastructure (equipment, software, maintenance and networking) across customers. MaaS is based on real-time insights into the status of manufacturing equipment, retrieved through ML techniques; big data streaming technology will transfer this essential information about production and shop floor to the cloud computing platform. This information will accurately represent the manufacturing context by help of digital twin software.

All these aspects are presented in the book. We think that students, researchers and engineers will find this volume useful for the study of digital manufacturing control.

October 2020

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