Simulation and the Fourth Industrial Revolution

Murat M. Gunal

Abstract Through history, advancements in technology have revolutionised manufacturing and caused a leap in industrialisation. Industry 4.0, the Fourth Industrial Revolution, comprises of advanced technologies such as robotics, autonomous transportation and production machinery, additive manufacturing, Internet of Things (IoT), 5G mobile communication, sensors, systems integration, Cloud, big data, data analytics, and simulation. Such technologies are used in the production of quality goods, which increased product diversity, and often at lower costs achieved through optimisation and smart production techniques. The goals of Industry 4.0 are to achieve Smart Factories and Cyber-Physical Systems (CPS). The introductory chapter presents concepts from Industry 4.0 and contextualises the role of simulation in bringing about this new industrial age. The history of the industrial revolutions and simulation are discussed. Major concepts in Industry 4.0, such as CPS, vertical and horizontal system integration, Augmented Reality/Virtual Reality (AR/VR), Cloud, big data, data analytics, Internet of Things (IoT), and additive manufacturing are evaluated in the context of simulation. The discussions show that computer simulation is intrinsic to several of these Industry 4.0 concepts and technologies, for example, the application of simulation in hybrid modelling (e.g., digital twins), simulation-based training, data analytics (e.g., prescriptive analytics through the use of computer simulation), designing connectivity (e.g., network simulation), and simulation-based product design. Simulation has a pivotal role in realising the vision of Industry 4.0, and it would not be farfetched to say that simulation is at the heart of Industry 4.0.

Keywords History of simulation · Industrial revolution · Industry 4.0 · Hybrid modelling · Cyber-Physical Systems · Digital twin

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M. M. Gunal (ed.) *Simulation for Industry 4.0*, Springer Series in Advanced Manufacturing, https://doi.org/10.1007/978-3-030-04137-3_1

1 Introduction

Technological advancements through the last decades have radically transformed our daily lives. Taking the example of the Internet and mobile telephony, the latter made it possible for people to be connected 'on the move' through voice calls and text messages, whereas mobile Internet allowed access to the *World Wide Web* without the need for either a wired or a static Internet connection. Technologies such as these have created a new kind of economy; an economy that is characterised by the speed of access to information, an economy where consumers demand faster deliveries and up-to-the-minute information on products, prices/sale, user comments and feedback, tracking information and so on so forth. To cater to such evolving dynamics of the market economy, businesses have been forced to redesign their business models and the underlying systems for the manufacture and delivery of goods.

Industrial revolutions take place as a result of significant changes in technology and the way people live. The first Industrial Revolution was triggered by inventions of machines powered by steam engines, and this led to an increase in production. The second revolution was about electricity and mass production of goods. The third revolution was mostly about the use of electronics in production. As manufacturing systems were increasingly controlled through electronics, this reduced the need for labour—however, production continued to increase. The first three revolutions were not explicitly started, or they did not expressly end. Indeed, they were named as "revolutions" subsequent to the industrial transformation having begun or after they had ended. These were silent revolutions which, over the subsequent years and decades, have continued to increase welfare.

The fourth Industrial Revolution, Industry 4.0, is about revolutionising manufacturing by making machines that are connected and smarter. The main objective of Industry 4.0 is to create "smart factories" and "Cyber-Physical Systems (CPS)". In smart factories, there are autonomous machines which can convey routine jobs as well as decide what to do in exceptional situations. They can inform the time to replenish stock and the inventory-level to maintain, and switch between different tasks easily. Rüssmann et al. [19] emphasise nine technologies which will drive the new industrial revolution. These are big data and analytics, autonomous robots, simulation, horizontal and vertical integration, industrial Internet of Things (IoT), cybersecurity, the Cloud, additive manufacturing, and augmented and virtual reality (AR/VR). Although the aforementioned technologies already exist, we are going to need more of this to achieve Industry 4.0 objectives; it is therefore expected that the next decade will witness major advancements in these technologies and indeed the development of new Industry 4.0 technologies. For example, robots are common in manufacturing, but robots in the future will not require human intervention for decision making. This is rather difficult today but the advancements in Artificial Intelligence (AI) and sensor technology has the potential to make this happen. We will have changes in way of thinking in manufacturing, for example, there will be a change from preventive maintenance to predictive maintenance. "Predictive maintenance" will alleviate the need for periodic maintenance, since machines will "predict" when they are going to need maintenance to be scheduled. A comprehensive review of the academic literature and introduction to the Industry 4.0 concepts is presented in Liu and Xu [15].

Compared to the first three industrial revolutions, Industry 4.0 is a very different revolution. First, it is announced in 2011 and therefore it has an explicit start date. Although the name was coined in Germany, it is adopted by many other nations. Secondly, it is an industrial revolution which arises from one of the greatest inventions of mankind, the Internet. Thirdly, this new revolution is associated with autonomous machines. Humans controlled machines in earlier industrial revolutions, but with Industry 4.0, machines have gained intelligence and autonomy. The control is thus handed over to machines in manufacturing.

The impact of Industry 4.0 on the global economy is expected to be transformative. A survey conducted by *PwC* [9] with over 2000 participants in 26 countries reveals that companies are likely to invest \$907 Billion per year on digital technologies such as sensors, connectivity devices, and software for their manufacturing systems, and expect \$421 Billion reductions in their costs and \$493 Billion increase in annual revenues. Moreover, *Boston Consultancy Group* (BCG) predicts that the new industrial revolution will make production systems 30% faster and 25% more efficient. Furthermore, it will create 390,000 new jobs and an investment of €250 Billion specific to manufacturing [19].

After the announcement of Industry 4.0 (in Germany), working groups were formed. Guides were published for decision makers to provide them information on realising the potential of transformative technologies associated with this revolution. Kagerman et al. [13] report the current situation of manufacturing in Germany and recommends steps for change. Other nations responded to Germany's move, but mostly accepting the idea of revolutionising manufacturing and going digital. In the USA, *Advanced Manufacturing Partnership* (*AMP*) initiative was formed in 2011. This was a government initiative which aimed at bringing together industry and improving manufacturing in the US. Non-profit organisations, such as The *Smart Manufacturing Leadership Coalition* (*SMLC*), also formed with similar objectives. In China, a strategic plan called "*Made In China 2025*" was developed with the aim of upgrading manufacturing systems and focusing on producing higher value products in China. This initiative increased the use of robots in China. South Korea's perspective on Industry 4.0 is presented in Sung [22]. Japan proposed "*Society 5.0*", which is essentially an idea for making the society ready for the new digital era. Russia also discusses improving the use of technology in manufacturing with initiatives such as *National Technology Initiative*. Turkey has announced a road map for digitisation of the country, including the industry [16].

A key technology associated with Industry 4.0 is computer simulation. The word *simulation* comes from a Latin word called "*Simulāre*" which is the infinitive form of "*Simulō*", also in Latin. "*Simulō*" means "*I make like*" or "*I behave as if*". The action for "*making like*" or "*behaving as if*" is done either physically or virtually. For example, before the Age of the Computers, commanders simulated their war tactics and strategies using the physical representation of objects (such as battlefield assets) and placed them on maps. They wanted to rehearse the actions they would do during the war and discuss possible situations with their commanders. With the advent of the computers, such war simulations based on moving physical objects on maps have mostly ceased to exist; however, physical simulations continue to be used in other domains. For example, for medical training, healthcare simulations are used to train healthcare professionals using dummy human figures to mimic injuries. Even the hardware in simulators (human-in-the-loop and machine-in-the-loop simulations) are controlled mostly by computers.

The book is written to inform stakeholders of the industries of the future, of the significant role of simulation in the fourth industrial revolution, including its application for supporting developments and implementations of manufacturing technologies associated with Industry 4.0. Simulation is directly related to CPS, digital twin, vertical and horizontal system integration, AR/VR, the Cloud, big data analytics, IoT, and additive manufacturing. Indeed, simulation is at the heart of Industry 4.0. This chapter is organized around related technologies and their intersection with simulation, after a historical outlook which evaluates industrial revolutions and simulation perspective.

2 Historical Outlook

2.1 A Brief History of Industrial Revolutions

A revolution is, in an industrial sense, an extraordinary growth and change in technology, or a leap in science. It is closely linked with scientific growth, both in terms of theory and application. The first revolution, the Industrial Revolution (1750–1870), caused an increase in the application of science to industry [5]. The change in the way how we produce was from agrarian and handicraft to manufacturing with machinery. Man-powered tasks could be done by machines which were powered by some other sources of energy, such as steam produced by burning coal. Steam engines, and later internal combustion engines which burn oil, produce power to drive machines of manufacturing.

During the first Industrial Revolution, the change was not only in science and technology, but it was also in the economy, social life, politics, and culture. Large-scale production meant more products at lower prices, and which translated to a new customer base. People became urban, and there was an increase in the living standard.

Exact beginning and ending dates for industrial revolutions are difficult to present as there are different views as to the start and the end of the revolutions. Figure 1 presents a timeline with the most agreed dates. For the first one, for example, the beginning date is related to the textile industry which was developed in Britain. It is said to end by the end of the 19th century with the inventions such as electricity and steel making process. These inventions and many others caused the second industrial revolution which eased manufacturing and enabled mass production. Some say the

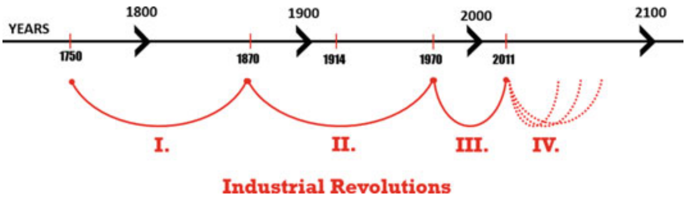

Fig. 1 Timeline of the industrial revolutions

second revolution lasts until the beginning of World War I (WWI) in 1914; however, its effects continued until the beginning of the third industrial revolution.

During the two World Wars and the Cold War period, the technology continued to develop in different parts of the World. Two most important innovations of the modern world occurred in this period; Digital computers and the Internet. By the 1950s, digital computers started to appear in many areas, including manufacturing. However, the beginning of the third Industrial Revolution is attributed to the invention of Programmable Logic Controller (PLC) in 1970. PLC had a great impact on automation in manufacturing. By the end of the 1980s computers started to appear in business which even supported the deployment of PLC in manufacturing. In 1960s, as part of the ARPANET project (defense), strides were made in computer networking that allowed computers to exchange messages. But the diffusion of this technology and its commercialisation only happened in the 1980s. Later in this era, the Internet has evolved and became a communication medium and information megastore. Personal mobile phones and "smart" mobile devices amplified the wind of change. Eventually we ended up with Information and Communication Technologies (ICT) era.

ICT helped improve manufacturing systems significantly in many ways. We did not need to spend time in front of machines anymore, but still, we needed to start machines and observe how things were going. Today, most manufacturing systems work like this, that is we still control manufacturing. In the fourth industrial revolution, however, the basic idea is to hand over the control in manufacturing to "smartness in machines". "Smartness" is a difficult term in many ways. At least, it requires awareness, synthesis, and rational decisions. Industry 4.0 technologies aims at achieving all these to end up with "smart factories".

The latest industrial revolution's beginning date is 2011. Germany is the founding nation, and the naming nation, of the Industry 4.0. Germany has thought that such a move was necessary to be able to meet the increased global competition. Rising production costs and improved quality in the competition have forced Germany to act and to create a road-map. Germany's objective is to achieve production of customised products and to lower fast time to market.

Is Industry 4.0 an Industrial Revolution? Most say "yes" to this question as many other nations made moves to reshape their manufacturing philosophies. The global economy and the level of technology support this idea that we are really in an era where we demand products differently than we did in the past. We want a product just like we want it to be (colour, shape, and configuration), and we want it right now. It is normal that the manufacturing must adjust itself accordingly. Industry 4.0 is, therefore, a revolution in the industry. Not only in terms of how humans demand the end product but also how we manage, transport, and produce things, and live.

Thinking of “4.0”, a couple of sentences can be written about it. Versioning the technology-related products and concepts, which originally comes from the software world, is a fashion. For example, Web 2.0 is used to name the new developments in web standards. It is true that once a version of a product or idea is released, it can affect its surrounding domains. Health 2.0 and Medicine 2.0 [25] are developed as a result of Web 2.0. This behaviour is similar for Industry 4.0. We have now Retail 4.0 [11], Telecommunication 4.0 [27], and Health 4.0 [24]. These ideas are influenced by the Industry 4.0. Signifying an idea with versioning is common today. The government in Japan introduced a plan named Society 5.0 to transform society [6]. The program claims that it is now time for a new kind of society (5.0) since industrial (3.0) and information (4.0) societies are no longer exist.

Causes and effects of four industrial revolutions are summarised in Table 1. The third revolution is over since we are ready for something very different in the industry. We have now “smart digital signals” in place as our machines can decide what to do next. The technology’s current state allows us to make manufacturing transform. For a more detailed evaluation of the first three revolutions, from governance and technology perfective, please refer to von Tunzelmann [26].

Industry 4.0 is different than previous industrial revolutions in terms of its beginning. No other industrial revolution had been explicitly announced. Industry 4.0 might seem curious in this regard, but this also indicates its two attributes; proactive-

Table 1 Cause and effect relation of industrial revolutions

	Causes	Effects
First revolution 1750–mid 1800s	Steam engine powered by **water**	Mechanize production, iron and textile production
Second revolution 1870–1914 (start of WWI)	Electrical motors powered by **electricity**	Mass production, steel making process, large scale machine tools manufacturing
Third revolution (1970–2011)	Electronics circuits, Programmable Logic Controller (PLC) and Information and Communication Technology (ICT) derived by **digital signals**	Production automation, human controlled manufacturing
Fourth revolution (2011–)	Cyber-Physical Systems (CPS), advanced automation and robotics, Artificial Intelligence, Internet of Things (IoT) derived by **smart digital signals**	Autonomous manufacturing, connected businesses

ness and creating a vision for the future. We have not seen the effects yet, but with its vision, we are expecting to see the desired future.

Do we know when this revolution will end, or what and when will be the next industrial revolution? We do not know the answer to this question. But examining the time between industrial revolutions, the hops in Fig. 1, we see them getting shorter. Does this mean we are going to see new industrial revolutions soon, and frequently?

2.2 Simulation Perspective in Industrial Revolutions

Computer simulation, as we know simulation today, dates back to the beginning of the 1950s, the post-World War era. There was a need for analysis of randomness in military problems and stochastic simulation foundations laid down by mathematicians. Computer simulation was started to be used by steel and aerospace corporations to solve complex problems with very complex models. These models could be run by highly skilled people and on mainframe computers. General purpose programming languages, such as FORTRAN, and later specialised simulation languages and software, such as "General Purpose Systems Simulator (GPSS)" and SIMSCRIPT were used to create simulation models. Discrete Event Simulation (DES) was in the heart of these languages, and indeed it is still in there in most modern simulation software.

Although the emergence of simulation has been during the second Industrial Revolution, its use and spread had started with the third Industrial Revolution, in the late 1970s and early 1980s. It was first used in automotive and heavy industries. More people showed interest and large events were organised, e.g., the *Winter Simulation Conference*. The conference program included tutorials, which helped to disseminate "simulation" in these conferences to the people in the industry. Simulation courses were designed and students could enrol in such courses at universities.

During the 1980s, simulation community was interested in Material Requirement Planning (MRP) and process planning in factories. There were very limited graphical representations and most simulations were run textually or numerically. With the advancements in computer graphics in the 1980s, animation became an integral part of programs that were used to develop computer simulations. Factory processes could now be simulated with animation added so that the stakeholders (e.g., factory managers, workers) were able to observe how their factories would function when some changes were done to the underlying processes. Animation helped in further dissemination of simulation as a tool for decision making.

Computer graphics revolutionised simulation. Simulation by numbers turned to iconic animations, and then to 2 dimensional (2D) animations. First simulation software with graphical user interfaces (GUI) such as Arena and Micro Saint could run on personal computers with Windows operating system. They had, which they still have, drag and drop modelling objects on the screen to build simulation models, and iconic and 2D animations to show models run. In the early 1990s, these features were remarkable for modellers and decision makers. In today's simulation software world, there are many simulation software in the market. The web site https://www.capterra.com/simulation-software/ is a good source for a list of simulation software.

The first decade of the Millennium, the 2000s, were the years of Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) software. CAD/CAM software became a part of product design and manufacturing. Advancement in these software products created a base for Industry 4.0. Simulation also evolved with CAD/CAM software, and 3D visualisation became a standard feature in DES software. 3D Models can now be used in simulation models and create realistic visualisations. Inversely, some CAD/CAM software can simulate dynamics of the objects they represent. The integration between simulation software and other utility software can also be seen in Enterprise Resource Planning (ERP) software.

Simulation has grown with the third industrial revolution and made itself ready for the fourth revolution. In the Industry 4.0 era, it is expected that computer simulation will become a significant driver of the progress.

3 Simulation and Concepts of Industry 4.0

Industry 4.0, as it was introduced in 2011, has many concepts and technologies involved, and it is difficult to come up with an all-encompassing list. Here, we list some of the concepts and technologies agreed in the literature [4] and discuss their intersection with simulation. We can extend the list, since Industry 4.0 and digitisation in manufacturing are evolving with more ideas which are going to affect the future.

3.1 Cyber-Physical Systems (CPS) and Digital Twin

CPS is a platform of collaborative industrial business processes and networks which regard smart production systems, storage facilities, supplier organisations, final demand points at people's fingertips. CPS include smart machines, processes, factories and storage systems which can autonomously exchange information and take necessary actions such as running, replenishing, ordering, and transferring tangible goods [13]. Another definition of CPS is about the marriage of mechanics, electronics and software. It is the blend of software with mechanical and electronic devices which can communicate through a data exchange medium.

"Digital Twin" is used as a term which denotes controlling software part of CPS. In CPS, physical devices can be controlled by a software replica which can communicate with these devices in real-time. For example, a button in Digital Twin can make a machine on and off.

A Digital Twin is not only for controlling devices but also for processing the data collected from devices. Talking about "software replica", a Digital Twin is a simulation of the system that is replicated. A Digital Twin cannot only act in real-time but also can predict the effects of the action. In CPS, the role of a Digital Twin

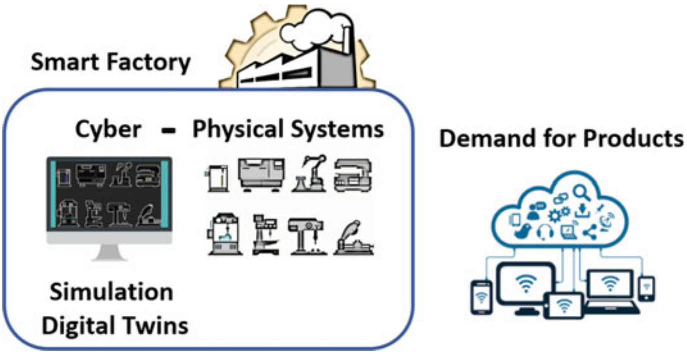

Fig. 2 Cyber-Physical Systems and simulation

is to simulate in the virtual world and predict the possible outcomes of that action. Human users, or Artificial Intelligence (AI), will be aware of risks before the action is taken, and eventually, make the right decisions.

In the CPS concept, there is an exchange of data between devices and Digital Twin. This exchange makes Digital Twins “real-world aware” and therefore valid representations of reality. Simulation is valuable with real-world data (Fig. 2).

3.2 Vertical and Horizontal Systems Integration and Hybrid Modelling

Factory of the future, the Smart Factory in Industry 4.0, must have tightly coupled systems which require two types of integration; vertical and horizontal. Vertical integration means that the systems within a smart factory must be aware of each other, and manufacturing systems and products must be hierarchically organised. Horizontal integration means that smart factories, and businesses, must be networked and cooperate.

Figure 3 illustrates that comprising systems in a smart factory work individually but also collaboratively. They are linked via high-speed connection systems, and exchange information obtained by sensors. Machines up-stream and down-stream processes tell their states to other machines. Machine states and times of state changes are significant to make machines prepared for future jobs. Sensors are critical components because they collect real-time data from machines, which are then transmitted using Internet of Things (IoT) technologies.

Vertical integration is about linking machines, making them aware of other machines, and more importantly, governing them centrally. The governance does not mean taking full-control of machines but rather orchestrating them to increase efficiency and reduce waste. Lean Manufacturing concepts, therefore, are very appli-

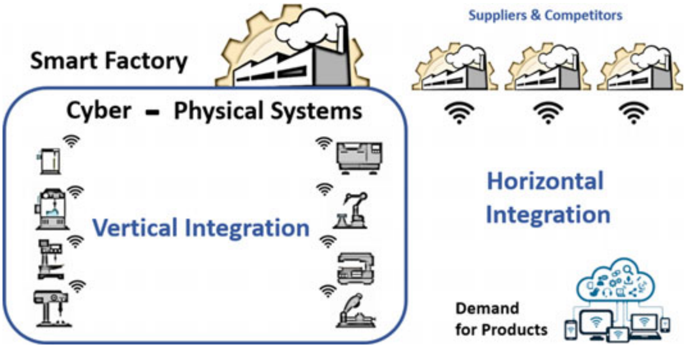

Fig. 3 Vertical and horizontal integration

cable to Industry 4.0 concepts in general. CPS represents not only the comprising components of a factory but also a central authority to govern a factory.

Horizontal integration is about linking factories and customers. This type of integration is difficult for many reasons. First, we are opening our factory information to the outside world and therefore confidentially might be breached. This brings the need for information security or cybersecurity. We need integration with suppliers for speed; however, we must carefully evaluate cybersecurity issues.

Simulation is used to make vertical and horizontal integration happen. It can be used for designing, testing, and evaluating integration systems. For vertical integration, a digital twin includes machine models which can help evaluate how machines can integrate. Simulation models can tell what data a machine is needed to generate and why is that needed. This type of use of simulation is for pro-active purposes. Simulation is used before integrating machines so that the level of vertical integration can be designed and evaluated. Questions such as "Do we really need this sensor on this machine?" or "What will we achieve if we integrate our machines?" can be answered by using simulation models. Simulation can also answer questions for re-active purposes, such as "What happens to our throughput if a machine breaks down unexpectedly?"

For horizontal integration, we mainly talk about "Supply Chain simulation". A factory needs raw materials, or components, from suppliers and it is crucial for manufacturing to have them ready on-time. Supplier relations are also important for maintaining quality. You depend on your suppliers' quality. Supply Chain simulation models can help design and evaluate your integration with your suppliers. Questions such as "which suppliers should we work with to reduce our costs?" or "What information should our suppliers get to integrate with us?" can be answered by using simulation models.

Another type of simulation models we need is about integration with customers. In this new era, as discussed before, the type of demand from customers has changed. Products demanded are now customised and required instantly. Simulation models can be used to evaluate the effects of changes in the market.

The need for simulation is obvious but how do we simulate all these? We talk about multi-level of details in systems. The answer could be in hybrid modelling [17, 18] methods and multi-resolution/hybrid simulation models [3]. For example, we need different time granularities in models; milliseconds for the physics of goods in manufacturing, seconds for the operations at the machine level, and minutes for the process level. Likewise, we need different way of modelling; DES for modelling factory processes, and System Dynamics (SD) and ABS for understanding customer dynamics.

3.3 Augmented Reality/Virtual Reality (AR/VR) and Training People

The term Augmented Reality (AR) is first used in 1992 by Caudell and Mizell [7] to describe a technique which superimposes computer-generated graphics onto real objects with displaying devices such as goggles, helmets, monitors, or hand-held devices. AR devices are first produced for the aerospace industry and applied on heads-up displays. Azuma [1] state that AR systems have mainly three characteristics. They can combine real and virtual objects, they can interact in real-time, and they use 3D computer generated objects. Syberfeldt et al. [23] classifies AR hardware into three groups; Head-worn, hand-worn, and spatial. The technology is not new, however recent trends show that AR is becoming more popular. Billinghurst et al. [2] survey 50 years of computer-human interaction in AR research context.

Karlsson et al. [14] is an example of decision support tool capable of AR. They displayed a traditional DES model's 3D view on a table with Microsoft's HoloLens. On their display, they showed a 3D view of a manufacturing facility and a score for the cause of bottleneck on each machine. Rather than displaying the simulation execution in real-time, they displayed pre-executed simulation results on a table. This is ideal for a group of decision-makers who evaluate options for better manufacturing. They claim that AR provides better comprehension than traditional visualisation tools such as bar charts, and AR can be used in training, collaboration, production planning. They report an increase in performance of trainees using AR devices.

In Virtual Reality (VR), the user is immersed in a virtual world made of computer-generated graphics. The user can visually, through eyes, sense the virtual world and interact with virtual objects. It is an improved way of visualisation in a simulation. Rather than observing virtual objects on a 2D screen, the user feels the sense of the 3D world.

AR/VR, as illustrated in Fig. 4, are a part of CPS. They are seen as optional today, however, in the future, they are going to be required in CPS. With VR, the simulated world can better be displayed so that the users can comprehend the cyber world and make changes in the physical world. "Fidelity" in VR is an issue to tackle. In fact, the fidelity issue is solved with AR. In AR, computer graphics is supported by the objects in the real world, and only necessary cyber, and visual, objects are created. It

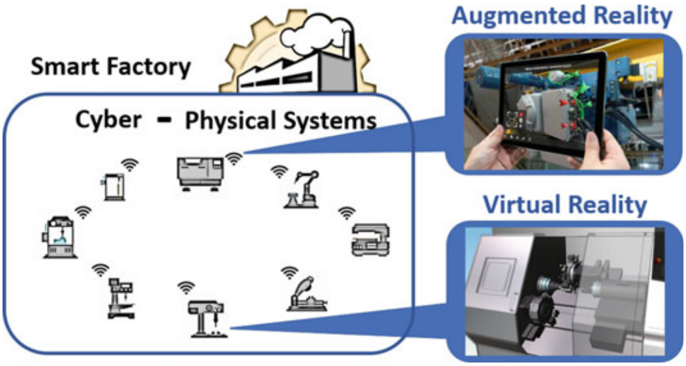

Fig. 4 Augmented Reality (AR) and Virtual Reality (VR)

can be speculated that if we had high fidelity VR systems with the ability to interact with the real physical world then we would not need AR.

Other than AR/VR, there are physically established simulation centres to train people who work in Industry 4.0 enabled factories. Faller and Feldmüller [8] reports a training centre for SMEs in Germany to make them ready for Industry 4.0. They use simulation in the training centre to mimic a few processes in a factory, such as robotic actions.

3.4 Cloud, Big Data Analytics and Simulation Input Modelling

The Cloud and Big Data are the two terms which are frequently discussed today. It is true that, because of electronic devices, there is more data available today than we had before. The devices and services we use, such as mobile phones and the Internet, produce data and presents an opportunity for scientists. Data Analytics (DA) is a growing field in computing science which deals with the analysis of non-trivial amounts of data. It relies on methods and algorithms which can deal with large data sets.

Simulation models require data from the systems they represent. This requirement is due to the need for making models realistic. Historical data is used to create statistical inference which provide inputs to simulation models. Overall process is named as “Input modelling” in simulation literature. Input modelling is as old as simulation itself. In the early days of simulation, data from the system on hand was analysed to study probability distributions in stochastic processes. Probability distributions are needed in systems where there exists variability and randomness, such as in random arrivals of supplies and orders, the occurrence of failures, and process times of jobs.

There is still a need for data analysis for increasing our understanding of systems, not only for simulation but also for comprehension.

In an era where more data is available, we can create "better" simulation models, "better" in the sense of realistic data collected from industrial systems. The task of data collection is now fulfilled by using technologies such as sensor and IoT. However, standardisation in data collection is an issue. For this purpose, there are studies conducted by organisations such as the *Simulation Interoperability Standards Organization* (*SISO*). SISO [21] publishes standards such as "*SISO-STD-008-01-2012*" for creating *Core Manufacturing Simulation Data* (*CMSD*) file in XML format. Likewise, as a result of international efforts, the standard *STEP-NC AP238* is created as a communication medium between CAD files and machining requirements in Computer Numerical Controlled (CNC) processes. Another international organisation, International Society of Automation (ISA), founded in 1945, develops standards for automation, such as "Enterprise-control system integration—Part 1: Models and terminology" in *IEC 62264-3* [12].

Simulation can also be used in DA, as summarised in Shao et al. [20]. Simulation can be used to analyse data for diagnostic, prediction, and prescriptive analytics. To diagnose an incidence in a manufacturing system, and to understand why this happened, sensitivity analysis using a simulation model can help answer questions. To predict the effects of a change in a system, and to estimate what this change cause, a model can simulate changes and tell what is going to happen. To enhance benefits gained in DA, a simulation model can run what-if scenarios and many alternative solutions can be evaluated.

3.5 Internet of Things (IoT) and Designing Connectivity

IoT makes objects communicate with each other and with humans. Although there are many other related terminologies such as the Internet of Everything (IoE), Internet of Goods (IoG), Industrial Internet, and Industrial Internet of Things (IIoT) [10], there seems to be a consensus on "IoT" in Industry 4.0 context. Manufacturing machines, transporters, storage systems and even products can communicate and exchange information with IoT technology.

With IoT, Peter Drucker's dreams may come true as once he said, "If you can't measure it, you can't improve it". From a management point of view, IoT provides real-time data from resources and processes which are needed for measuring things. We can keep track of our manufacturing assets including equipment, raw materials, goods from suppliers, and workforce. This valuable data can be used for utilizing things more efficiently.

IoT helps things to be smarter. Machines can be aware of their parts, with embedded sensors, and can predict when maintenance is required. This helps manufacturers do predictive maintenance rather than preventive maintenance. Raw materials stored on racks can be tracked and when they run out, new orders from suppliers can be given. Self-ordering supply systems are possible with IoT technology. Even products on production lines in factories can be aware of itself, and be smart. A product can question itself if anything is missing on it and can ask process control to complete the missing parts or help control the sequence of jobs in the production line.

Simulation can be used for designing and implementing IoT technology. Expected benefits of using IoT in factories can be tested using simulation modelling. A simulation model of a factory with and without IoT can show differences between the two worlds, and help investment decisions. Since simulation models are scalable, partial IoT implementations can also be evaluated with simulation. For example, a question like "what benefit can we gain if we track our finished products in our warehouse" can be answered by using simulation.

Simulation is a preferred method for designing IoT technology. There are simulation packages available in the market which helps developers to test IoT hardware. Using this simulation software, tuning IoT devices is possible. Additionally, research for 5G (5th Generation) mobile communication technology also use simulation for designing.

3.6 Additive Manufacturing and Product Design

Additive Manufacturing (AM) is a general term used for making 3D objects by adding forming material layer-upon-layer. It is a new way of manufacturing. It is mostly known with 3D printers. The material used in 3D printers today is typically a type of plastic which can melt, shaped, and cooled down. When the material is melted, semi-liquidised material is laid on a surface in a controlled way. CAD software, to design the object and layer laying device to shape the object are the two main elements of AM.

The material in AM has a substantial role since a "mould" does not exist in AM. Today we even see metal material used in AM. The future of AM is about new composite materials that can compete with materials in conventional manufacturing (Fig. 5).

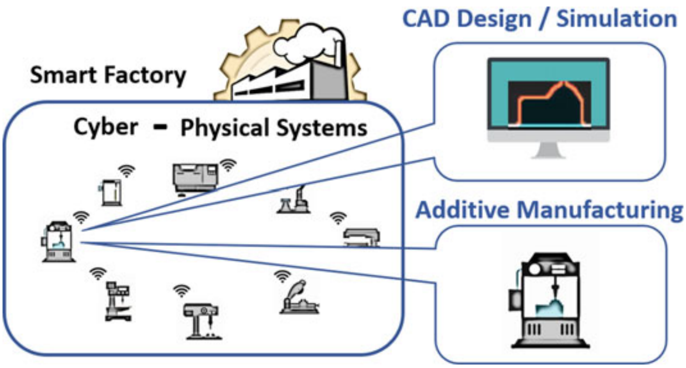

Fig. 5 Additive manufacturing and simulation

Simulation in AM takes place in the design phase and pre-manufacturing phase. Design of the object to be manufactured is done using CAD software. If the object is a component of a product, then the object's mechanics, such as moving area and assembly status, can be simulated in CAD software.

In the pre-manufacturing phase, 3D Printers software simulate the printing job, to avoid material loses and to test stability. These software work with CAD software and simulate layer forming process.

4 Conclusion

Industry 4.0 encapsulates many advanced technologies and aims at using these technologies to make manufacturing smarter, autonomous, cyber, and integrated. Smart Factories and CPS will realise these objectives by using robotics, big data analytics, cloud computing, IoT, systems integration, AR/VR, and simulation.

CPS is about digitising physical resources, mechanical and electronic parts of machines, with software and creating a replica, Digital Twin, in cyberspace. A Digital Twin is a simulation model of the manufacturing facility. It gets data from the real world and manipulates to create actions. Before taking action, systems can be simulated with Digital Twin to observe the effects of possible changes.

Vertical and horizontal integration in CPS is required to connect physical world entities. Vertical integration is to make a factory's components to be aware of each other to create a smart factory. Horizontal integration deals with inter-smart factory communication. Hybrid modelling and hybrid simulation could be used to realise these connections by testing alternative integration modes and operation scenarios.

AR and VR have great potentials in Industry 4.0 since they help create a cyber world in manufacturing. In this world, decision making and training can be done non-traditionally with more visual features. AR and VR are methods that create simulations of reality.

We need data analytics for obtaining inferences with data collected through IoT. Simulation helps create inferences. Additionally, simulation is a tool for designing connectivity using IoT devices. Simulation has been used in designing computer networks in the past.

Additive Manufacturing is transforming conventional product design process. With CAD software, a product, or a component, can be designed and simulated for its dynamics. Although 3D printers are used today mostly for rapid prototyping, they will be the main manufacturing machines in the future. The print process is simulated before physical activity, to increase efficiency.

For reasons discussed earlier on versioning (refer to the section on the history of industrial revolutions), we are not going to call this era "Simulation 4.0". However, we can prognosticate that simulation is entering a new era with the advent of Industry 4.0. As we get more digitised, we will see more simulations in the future. New uses and needs of simulation will emerge in manufacturing in Industry 4.0 era, and simulation research community must respond with new methods, algorithms, and approaches.

Acknowledgements I am grateful to Dr. Navonil Mustafee from University of Exeter for his constructive comments, and for improving the language.

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