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Industry 4.0: Eyeing The Future via Simulation

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Industry 4.0: Eyeing The Future via Simulation

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Abstract. Industry 4.0 is a future agenda. Currently, Industry 4.0 has paved the way in many industries around the world. Many initiatives have been put forward and assessed to ensure Industry 4.0 is becoming a reality. Although widely discussed in the both academic literatures and industrial publications, Industry 4.0 is encapsulated with many terms since it's inception. Some of the terms are not self-explained and often overlapped or even contradicted with similar terms in different perspectives. To demystify the issue, this paper begins with a brief overview of Industry 4.0 background including its importance and readiness. It reviews not only the technological concept with the support of nine pillars of prominent technologies, but also including the human resources as the driver behind the Industry 4.0. Dedicated section on how simulations can contribute to Industry 4.0 in ways where simulation applications can be combined with each Industry 4.0 pillars, including human resources are also presented. This paper is written in general view of Industry 4.0 so that it is easier to relate with not only with manufacturing sectors (which where Industry 4.0 was originally intended for) but also with other sectors.

1. Introduction

Industry 4.0 seems to be at the forefront of the discussion in both industry and academia. The topic is widely discussed even though it is still a non-consensual concept [1]–[3]. Industry 4.0 brings a significant long-term strategic impact on global industrial development. Industry 4.0 does not only confined to manufacturing sector but also impacted other sectors as well such as healthcare [4], agriculture [5], food industry [6], energy management [7], education [8] and perhaps many more.

The novelty in Industry 4.0 is not just in new technology but also include a various mixed combination of available technology in a new way [9]. For this, Industry 4.0 has raised high expectations, but to date, not all have been met yet. One way of doing the planning and assessing situation is through modeling and simulation. Simulation involves a process of imitating the system behavior [10]. Depending on the motivation of usage, various methodologies and techniques can be applied in simulation for the evaluation of complex systems [10]. Afterall, simulation is considered as one of the key pillars in industry 4.0. Therefore, how simulation can support in Industry 4.0 is reviewed too in this paper. Although most literature regarding Industry 4.0 are heavily emphasising on manufacturing sectors, this paper is intended to maintain the focus on the general view of Industry 4.0 so that it is easier to relate with other sectors too.

The remainder of this paper is organized as follows. Section 2 provides an overview of Industry 4.0 background, concepts, importance and readiness. Section 3 presents on how simulations can contribute to Industry 4.0. Lastly, this paper ends with closing remarks in Section 4.

2. Industry 4.0

2.1. Background and concept

Generally, the term 'Industrie 4.0' or 'Industry 4.0' is referred to as 'The Fourth Industrial Revolution' [3], [8]. To date, Industry 4.0 is still a new concept compared to the first three industrial revolutions which have spanned more than 200 years. The first industrial revolution or 'The Age of Steam'[11], began in United Kingdom [12], [13]. At the time, water and steam were used to power mechanical engine systems in ships, trains, production plants and manufacturing factories [12]. The second industrial revolution or 'The Age of Electricity', was driven by electrical energy. The movement started in Europe and US[13]. In this era, the application of electrical devices and internal combustion engines were used to support industries for mass productions [2], [11]. The third industrial revolution was driven by the Programmable Logic Controllers (PLC) and computerised IT systems and automation for digitalisation [9], [11]. Automated machines and computer applications were more widely used across the world in Industry 3.0 compared to Industry 2.0 [12]. Thus, this era is known as 'The Information Age'. As Industry 3.0 is matured, it becomes the foundation for Industry 4.0 to move forward, which is now, it is paving it's way to reality [2], [11]. A brief overview of the four Industrial Revolutions evolution is shown in Figure 1.

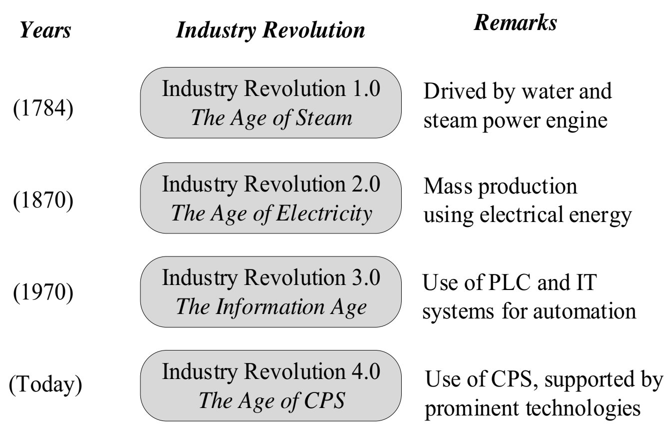
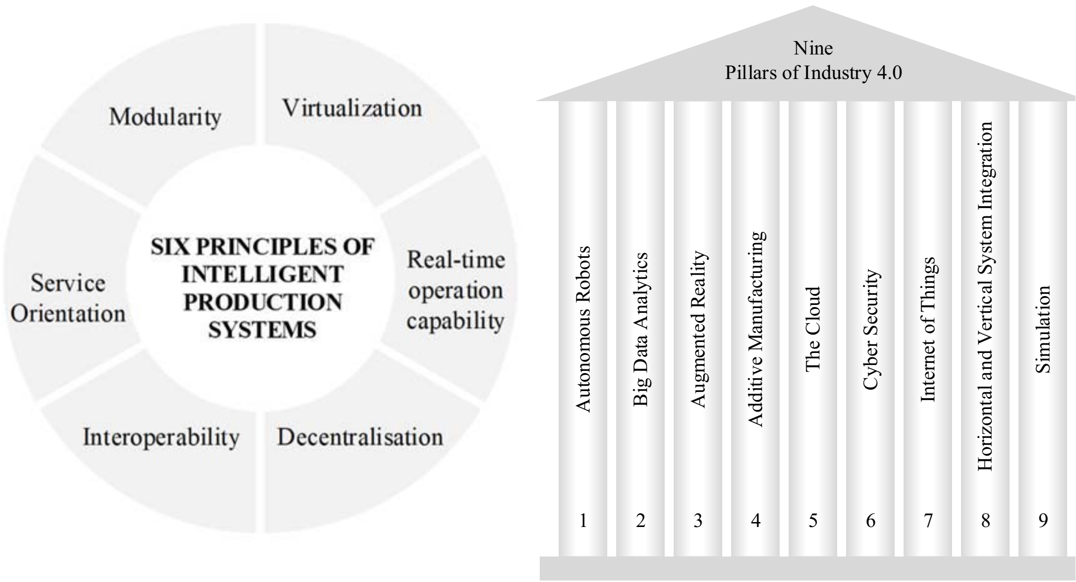


Figure 1 Overview of four Industrial Revolutions evolution, adapted from [2], [11]

Looking back at history, 'Industry 4.0' denotation was first coined by the German government as key initiatives that marked the new beginning of the next industrial revolution [9], [14]. Originally, Industry 4.0 is meant for Cyber-physical Production Systems (CPS) applications for Smart Factory [9]. The ideas are to use smart monitoring systems in production processes to support decision making, to lower down machine maintenance costs and to increase the competitiveness of German's industry. Besides technological aspects, human capital is another Industry 4.0 driver [15], [16]. Human labor ship will be assigned where human expertise is needed. Since the first announced in 2011 in Hanover Fair, Industry 4.0 has become the central focus of future industrial development [9], [11], [14].

Technological wise, there are six principles of intelligent production systems for Industry 4.0 development and deployment in the future have been recognised [16]. The six principles identified are illustrated in pictorial form in Figure 2(a).



(a) Six principles of intelligent production systems for Industry 4.0. [16]

(b) The nine pillars that support Industry 4.0. [2], [17]

Figure 2 The principles of intelligence production systems and the nine pillars of Industry 4.0 in pictorial form.

Each principle is explained as follows:

- Interoperability – allows information exchange between machines and machines, between machines and processes, and between machines and humans (through interface) in both physical and virtual worlds.
- Real-time operation capability – allows factory or business operation in real-time manners with instantaneous data acquisition and processing. Thus, this can encourage real-time decision makings as well.
- Virtualisation – allows remote traceability and monitoring of all operation processes.
- Decentralisation – allows smart application modules to work in a decentralised manner to improve production processes.
- Service Orientation – deploys service-oriented software architectures coupled with the IoT concept.
- Modularity – allows flexibility to change machine tasks easily where production processes can be designed according to the demand and where coupling and decoupling of modules in production can be done quickly.

Based on the six principles in Figure 2(a), Industry 4.0 is supported by the nine pillars of prominent technologies in Figure 2(b). All nine of them constitute the critical enabler of industry 4.0 implementation. These are the core which allows connections of machines, products, systems and people. Each pillar is explained briefly as follows:

1) Autonomous Robots:
With CPS, there was speculation that factories of the future would operate autonomously where less human intervention is needed especially on the tasks that are beyond human's capabilities and the monotonous and repetitive tasks. [18]. With CPS, the tasks will be taken in charge by autonomous robots[9]. It will be no longer necessary for humans to perform tedious, repetitive activities. This will

help free up workforces and redirect them to manoeuvre the robots or do the tasks that robots cannot perform instead.

2) Big Data Analytics

Once IoT is fully implemented, a gargantuan amount of non-real-time data and real-time data will be generated. These 'data goldmines' has potentials to generate valuable insights. Many industries will need to organize, manage and figure out how to analyze in order to benefits from their data to suit their needs[1]. One way of doing this is through Big Data Analytics. Analytics for big data may include data minings, machine learnings, artificial intelligence (AI) techniques, applied statistics and perhaps many more [19], [20]. In fact, there also needs for more advanced data science and data analytics techniques to be developed and employed for better decision makings [11].

3) Augmented Reality

The augmented reality applications serve in various purposes ranging from visual arts and games to medical, military, navigation, sports and educations. For industrial purposes, the applications are narrowed down to e-commerce, administration, training and marketing. Augmented reality can be an essential element in the intelligent industry for operation executions. Together with augmented reality, real-time information is supplied to workers to improve decision making and work procedures [2].

4) Additive Manufacturing

Additive Manufacturing is the technologies that can build a new 3D object or a recreation copy of any other 3D object. This process is done by adding layer-upon-layer of material at a time. This technology plays an essential role in creating new materials. For instance, in production planning where evidently, it helps to visualise the material's creation process and advanced further by the creation of prototypes [17].

5) The Cloud

Cloud-based applications serve as a critical aspect for storage, connection and communication in digital connectivity and digital production. Three prominent Cloud applications are Software as a Service, Platform as a Service, and Infrastructure as a Service [21]. These Clouds can be either public, private or hybrid mode. Each has a variety of speed. On the application side of smart factory, "Digital production" offers a concept of having the connections of different devices to the same Cloud for information sharing. For example, administrators can store their data in the Clouds. And using the Clouds, they also can implement new systems to monitor the operations and to control processes. Meanwhile from the business perspectives, the Clouds also can offer a platform for digital connectivity through the concept of information sharing. For example, information with collaborators or customers. As results, this can lead to a transparent business ecosystem in competitive market environment.

6) Cybersecurity

Transparency can expose a company to vulnerabilities. Thus, information security and privacy protection are among top priorities in Industry 4.0. However, current existing technologies, may not be enough for future industrial applications. Cybersecurity has to comply to suit the company's safety, security regulations and standard requirements. Network security, information security and data privacy protection are critical aspects that future should take account before implementing IoT technologies and services in Industry 4.0 [22]. Access to production-related data and services has to be administrable to protect the company's intellectual property or intellectual know-how [9]. Besides that, it is also important to avoid illegal access to production systems, especially the ones that can cause environmental or economic damage and harm to humans.

7) Internet of Things (IoT)

Internet is the backbone of data communication in Industry 4.0 [21]. The introduction of information and communication systems for IoT into industrial network leads to a steep rise in the degree of automation and data sharing. When everything is connected, everything can communicate with one another. With digital product memories, a collection of data can be recorded in all phases of the product life cycle and can be saved for analysis. The information needs to be organized in all aspects according to territories, storages and aspects of usage such as Cloud, cybersecurity, simulation, augmented reality and perhaps many more[17]. With full IoT capabilities, many can reap the benefits of smart power grids, smart healthcare, smart logistics, and perhaps many more smart paradigms[21].

8) Horizontal and Vertical System Integration

Horizontal and vertical systems integration promotes a chain of collaborative systems. The chain may involve multiple combinations of units or departments. The combinations can be between engineering, production, suppliers, marketing, and supply chain operations and perhaps many more. In order to integrate the systems, there are two aspect that must be considered. First, is the levels of automation and second, is the information flow [17]. By far, there are three categories of integration identified in the literatures [2], [17] namely:

- horizontal integration across the entire value creation network: this means the information integration of business operation occurs at the same level of the business's value chain, either in a similar industry or different ones.
- vertical integration and networked manufacturing systems: this means the information integration of business operation involve across different level of the business's value chain, either upstream manner or downstream manner or both.
- end-to-end engineering across the entire product life cycle: this means the information and data can be obtained and analysed throughout the production process. This features is beneficial for quick decision makings.

9) Simulation

Simulation helps to evaluate the effects and impacts of actions in safe mode. It enhances learning and decision makings. The changes of behaviors in the configuration of machines, process flow and plant designs can be observed in the simulation environment. The effectiveness of the changes can be tested without them being realized in real-world [2], [17]. As Industry 4.0 is a complex environment, it is not a surprise that new paradigms is highly needed to support Industry 4.0 [23]. For this, models for simulation are expected to be smart, can perform self-correction, can be a learning system that is able to adapt behavior based on changing conditions and past experiences [24]. Furthermore, future simulation can be used for semi-autonomous problem solving [24]. There are also initiatives to combine analytical with simulation tools. In doing so, decision makers can evaluate options to take the best decisions.

2.2. Why Industry 4.0 is Important?

In term of a global perspective, Industry 4.0 significantly can influence economic growth and increases nation economic prosperity. Here are several reasons why Industry 4.0 is important in terms of business operations.

- Industry 4.0 encourages industrial processes to change for the better. For examples in manufacturing systems and supply chains. It promotes a new way of doing business or perhaps a new business value, especially for traditional business model organizations [1], [13], [25].
- Industry 4.0 cultivates decentralized and digitalized production in business operation [9], [15], [26].
- Industry 4.0 implementation help to increase competitive advantage. This can be achieved through the successful digital business model implementation and technology creation [27].
- With robots and automated applications, tasks completion are better and faster by machines rather than by people [9][13].
- The use of cutting edge technologies in Industry 4.0 such as digital chains, smart systems, centralized management and the industrial Internet will speed up innovations as new business models can be implemented much faster [9], [14], [27].

- In Industry 4.0, it is believed that things will become smarter, more reliable, and more autonomous. This will increase the added-value of businesses, especially on products and services [13].

2.3. Are we ready for Industry 4.0?

Smart systems, smart operations, smart productions, humans capitals in Industry 4.0 were identified as the peak priorities. To date, Industry 4.0 is still far in the future. Many ideas are still in the realm of fiction, but some are on its way to reality. Governments, industries and universities worldwide embrace the transformation era of Industry 3.0 and welcome Industry 4.0. There has been an increasing trend and research attention on the nine pillars [9], [11], [14], [22]. Efforts have been made to reap the benefits from what the new industrial revolution wave could offer.

By doing so, Industry 4.0 exposes established companies to new competitive challenges [18]. On the operational level, there is the need to explore more the possibilities and benefits of adopting or adapting the concept. Currently, most industries are facing the lacking of applicable frameworks for the implementation of Industry 4.0 [18].

On the business level, Industry 4.0 does not only concern about the issues on the technical sides but also on the management sides [22]. Many industries are not yet ready or mature for Industry 4.0. Some are still evaluating their readiness and capabilities towards implementing Industry 4.0. Decisions made have to properly analysed and studied before putting substantial investment in upgrading the business model to fit the Industry 4.0 concept. For some industries, this is a long way to go, and for some industries, the concept is still unknown. Many are aware that adopting and adapting Industry 4.0 comes with risks and uncertainties. The process involves many aspects and types of difficulties and challenges. These may stem from scientific sides, technological sides, and economic challenges, social problems as well as political issues [1].

On the national level, besides Germany, several other countries around the world were also have made their movements towards industry 4.0 [14], [27]. The countries include US, French, United Kingdom, some European countries under the European Commission, and some Asian countries such as South Korea, China, Japan, Singapore and Malaysia too. Table 1 is showing the national initiatives of several countries adapted from [14] with an extended update on Malaysia [28].

On the human aspects, most national Industry 4.0 initiatives by the countries mentioned are taking account humans resources as the centre of production. People is regarded as another Industry 4.0 catalyst [15]. Instead of looking at technology applications alone, it is worth pay attention at the people as the future depends on how the people are moving on the journey within the next few years or decades ahead [17]. Tasks slowly will be taken over by machines and robots. Most manual labours will be replaced by trained professionals or knowledgeable workers [16]. A knowledgeable worker is portrayed by World Economic Forum as a person who can deal with complex problem, think and judge critically, able to coordinate with others, creative and master digital skills [8].

Apart from human resources, politicians are among the important actors in shaping and supporting Industry 4.0 [15]. They play an essential role in including the different players in industries. One way of doing this is by creating a shared understanding of a future situation in economic sectors. Success stories are believed to be one way of getting business-minded people and entrepreneurs on board.

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Table 1. Government's National Initiatives on Industry 4.0 in several countries [14]

Year	Country	Industry 4.0 Plans	
		National Plan	**Aims**
2011	USA	Advanced Manufacturing Partnership	to ensure the US is ready to lead the next generation of manufacturing
2012	Germany	'High-Tech Strategy 2020' Action Plan	to gain competitive advantage, with billions euros worth of high-end technologies and developments for German's manufacturing
2013	French	'La Nouvelle France Industrielle'	focuses on 34 sector-based initiatives in France's industrial policy priorities
2013	UK	'Future of Manufacturing'	to provide a refocused and rebalanced policy for supporting the growth of UK manufacturing till 2050
2014	The European Commission	Pubic-Private Partnership (PPP) on 'Factories of the Future (FoF)'	providing financial support up to 80 billion euros under European Economic Recovery Plan from 2014 to 2020
2014	South Korea	'Innovation in Manufacturing 3.0'	contains strategies for a new leap of Korean's future manufacturing industries.
2015	China	'Made in China 2025'	prioritises ten fields in the manufacturing sector to accelerate the informatisation and industrialisation in China
2015	Japan	5th Science and Technology Basic Plan	for realising its world-leading 'Super Smart Society.'
2016	Singapore	RIE 2020 Plan (Research, Innovation, and Enterprise)	focuses on eight vital industries within the advanced manufacturing and engineering domain, which sets nineteen millions of Singaporean dollars.
2018	Malaysia	Industry4WRD [28]	to cultivate conducive ecosystem for Industry 4.0 technologies, and to ensure manufacturing sectors to be ready for Industry 4.0

3. How Simulation Can Help?

Computer simulation is considered as a safe platform to play around, learn, test assumptions and study and impact of particular actions chosen. The trends in simulation development indicated that simulation has moved to non-stand-alone paradigm instead using the former the traditional stand-alone paradigm [23]. To date, some of modeling and simulation approaches can be connected to various data sources, and output destinations [23], [24]. Some can be controlled and modified via user-friendly front-ends or other applications [23], [24]. For other cases, modeling and simulation is no longer relying on single approach but also taking account to integrate with other approaches as well such as optimizations, machine learnings, data minings etc.

In simulation, "system" is referring to "what, from the real world, is being simulated" [29]. A system can be referred to anything such as people, machines or resources. Real-world system is modeled as close as possible and simulated to support testing, learning and decision makings. In relation to Industry 4.0, every system is linked to one another. Smart systems of Industry 4.0 are "systems of systems" not only from the holistic views but in detail views too. The systems and the systems related need to work smoothly in a proper way in order for overall systems to be working effectively [30]. Due to these reasons, smart systems really need simulation technology to design and assess the applicability before the real implementation takes place. This is because to test in real world would be very costly. The side effects would be unbearable and irreversible. Through simulation-based decision support tools, users or

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decision makers will be able to seek solution development, validation and testing for systems and individual elements of systems [23]. For this, simulation can be combined with the other eight pillars, including extra section on simulation and human resources. For examples:

a) Simulation and Autonomous Robots – Simulation can help to design the kinematics and dynamics of robotic manipulators. Such systems are not easy to be developed and could not be realized in real world easily. Only simulations on system-level can gain the necessary insights [30]. Autonomous robots are complex. It is not easy to understand reality with all of its complexity. One way of doing this is by building artificial objects and dynamically act out roles with them to realise intelligent systems. There are two identified categories of simulations tools for robotic systems: (1) tools based on general simulation systems and (2) special tools for robot systems. The former comes together with specialized modules and libraries, including user interfaces. The purpose is to ease robot systems development for simulation. Whereas the latter is for advanced usage and multitasking tasks. This may involve off-line programming, designing robot work cells, kinematic and dynamic analysis, mechanical design and perhaps many more. They can be specialized for special types of robots. Among the common tools used for simulation of the autonomous robots are Discrete event simulation systems, MATLAB/Simulink, Modelica modeling language [30]. Some are provided by robot manufacturers such as KUKA.Sim, V-REP, and GAZEBO, Emulate3D and perhaps many more [30].

b) Simulation and Big Data Analytics – Under Big Data paradigm, data-model can be built upon abundant data such as from real-time devices or information systems [24]. The "data model" is then can be simulated to understand problems and solve complex problems to support decision makings. Heavy computations, high complexity, and difficulties to model feasibly are among challenges faced in this domain. But for Industry 4.0, these open opportunities for discoveries of new modelling and simulation paradigms [23], [30]. This can be new in-depth analysis, new way of processing especially on large-scale data processing. At the same time, innovation of existing modeling and simulation methodology also can be enhanced and explored further.

c) Simulation and Augmented Reality – Both can be a great tool when combined together, especially for training, upskilling, learning purposes. Augmented reality can help to increase people‘s understanding. This is evidently shown in a study by [31], where augmented reality was used as a medium for displaying the simulation results and analysis. Another purpose for combining simulation and augmented reality is for The Teaching Factory concept. This concept is close to “Education 4.0” where Teaching Factory is aimed to polish students through real industrial problems [8].

d) Simulation and Additive Manufacturing - Simulation is important in additive manufacturing. There are needs for the implementation of computationally efficient techniques to predict, to study and to assess varying characteristics of newly produced components. Among common simulation used are Monte Carlo simulation, Cellular Automata, Discrete Element Method and perhaps many more.

e) Simulation and the Cloud - Companies can retrieve the data from the Cloud and carry on doing simulation without having to worry about enterprise-level software deployments, server upgrades, hardware and software licensing or other issues. If they are able to run real-time simulations of their entire factory or company’s operation in the Cloud and they could configure their simulation environment whether to include new machines, new staffs or not, and getting the answer in real-time. Thus, faster decision can be made whether the additions will make a difference to productivity and profitability or not.

f) Simulation and Cybersecurity – With everything is interconnected to the network, the system inside a factory is vulnerable for attacks. Simulation applications for cybersecurity can help to assess the risk in cyber network and the network behaviour.

g) Simulation and IoT. One of critical application in this area is for planning IoT. This because to build effective and smart services can be quite complicated. IoT networks are complex. IoT connectivity is influenced by the location where they are going to be situated geographically, network communication capabilities, and device availability for distributions. Thus, IoT simulation is necessary for planning and risk assessment. To name a few issues: capacity planning, what-if simulation and analysis, proactive management and support for many specific security-related evaluations. Agent-Based Simulation and Discrete Event Simulation are among perfect simulation paradigms that are usually used[10]. Aside of being applied in IoT, there is also an emerging technology regarding simulation and IOT such as Internet of Simulation, which is an extension of internet technologies in simulations [24].

h) Simulations and Horizontal and Vertical System Integrations. Designing Industry 4.0 systems is tedious due to its high dimensionality and complexity. Simulation of inventory, logistics and transport, and usage history of products can help to positively influence the production processes. The complexity of the innovation systems lead to the development of modern approaches of new modeling approach. Thus simulation is treated as tool for further designing, creating, and modifying real innovative systems of different levels of organization under the conditions of Industry 4.0.

i) Simulation and human resources - Every revolution creates worries over job losses. This happens to Industry 4.0 as well. Although robots and machine automations are handy, but at the same time it creates insecurities. At the other end, in some sense, they are perceived as threat to human employability. Due to this reason, human resources in Industry 4.0 is widely discussed in the both industries and academic literatures. Many efforts and initiatives have been made to analyse the consequences of Industry 4.0. The efforts cover not only on operational, indirect management tasks and activities but also on the social impacts on national and international basis [32]. Based on literatures, evidently, simulation can help to effectively plan for human resources management. For example, a workforce plan can be developed in a way that can satisfy organization's or national's needs in meeting the objectives for recruitment, deployment and promoting right employees at the right places at the right times.

4. Concluding Remarks

Industry 4.0 promotes a new era of opportunities, challenges with uncertainties in a highly dynamic competitive environment. This paper reviews the concepts of Industry 4.0 including the nine pillars technologies that support Industry 4.0 conception to reality. Although many efforts have been laid to welcome Industry 4.0 including the governments (national level), not many industries are ready to embrace the idea of Industry 4.0 to the fullest. As aforementioned, these may come from many factors which may include scientific, technological, and economic challenges, social problems as well as political issues as well. As one of the nine pillars that support Industry 4.0, simulation plays a vital role. Simulations are proven to work well for designing overlapping system functions, for decision makings, learnings, trainings and many more. In order to achieve this, several aspects must be considered such as suitable tools selections, combination methodologies, data(s), and techniques used. With extremely complex system of Industry 4.0, simulation is very much needed to create a room for safe system execution, hence prevent unnecessary complications and losses. That is the main reason why simulation is considered one of the pillars for Industry 4.0.

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