4th Industrial Revolution: Challenges and Opportunities in the South African Context

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***Abstract*—** A number of industrial revolutions occurred at different times in history. These industrial revolutions have resulted in accelerated economic growth and improved quality of life for people around the world. We are currently at the dawn of the fourth Industrial Revolution (4th IR) or Industry 4.0. Industry 4.0 is relatively different from the previous three revolutions, primarily because of the disruptive nature of the technologies driving it and the potential scale of its impact across many industries. The 4th IR is characterized by digitization, collaboration, automation, adaption and human-machine interaction. In response to this phenomenon, countries across the world, especially emerging industrial economies such as South Africa intend to capitalize on the fourth industrial revolution to leapfrog development. This paper aims to shed more light on the challenges and the state of preparedness of South Africa as a developing economy to Industry 4.0.

***Keywords* —** 4th Industrial Revolution, Automation, Digitization, South-African Industry, Technological Advancement.

I. INTRODUCTION

The manufacturing industry has experienced significant transformations over the past two decades following technological disruptions. Industrial production has evolved over the years from a mass production system implemented in the 1900s, to flexible manufacturing in the late 1990s and recently to a smart manufacturing paradigm. The technological innovations that precipitated the last three industrial revolutions were steam power, electricity and Information and Communication Technology (ICT) respectively. We are now at the beginning of the fourth industrial revolution (4th IR, or 4IR) which takes the digital revolution, which began in the third industrial revolution, up a notch. Specifically, it is much more than the application of ICT to achieve automation in the production process, but a complete digitization of manufacturing operations with the application of cyber-physical systems that are capable of self-cognition, optimization, and customization [1]. This suggests that industry 4.0 production systems or facilities will be highly adaptable and able to monitor and control the entire manufacturing process with little or no human participation using artificial intelligence (AI) and machine-learning (ML) algorithms. According to Schwab and Davis [2], the "Fourth Industrial Revolution is a new chapter in human development, on par with the first, second and third Industrial Revolutions, and once again driven by the increasing availability and interaction of a set of extraordinary technologies". The 4IR is characterized by a combination of several disruptive technologies that are obscuring the lines between the physical, cybernetic and biological worlds [3]. The fourth industrial revolution significantly transforms the manufacturing industry and offers manufacturers numerous benefits such as increased revenues, enhanced product quality, supporting innovation across many applications, energy-efficient and environmentally sustainable production, waste reduction, increased flexibility and enhanced safety in the workplace [1]. According to a report by McKinsey and company, cost and revenue improvements of between 15 – 20 % could be expected with the 4IR [4].

Naturally, the effects of the 4IR will not be restricted to the manufacturing industry but will arguably be felt in every other sector. Yet, the fourth industrial revolution is still more of a vision that reality, since, according to Schwab [5], it is still too early to state how the transformation will unfold. He however argues that a holistic and integrated response is required from all stakeholders. Despite the uncertainties surrounding industry 4.0, it is imperative that countries, especially emerging economies endeavour to implement the 4th IR sooner rather than later, as history has shown the importance of being an early adopter of new innovations, while at the same time avoiding "bleeding-edge" innovations. In order to exploit the benefits of this new industrial revolution governments and regulatory institutions have to quickly adapt and respond to it by providing an enabling environment and policies that will foster sustainable socio-economic development [6]. Since there is limited literature on the industry 4.0 with reference to South Africa, this paper aims to contribute to the existing body of knowledge on the 4IR by eliciting the preparedness and implementation challenges of the 4IR in South Africa as a developing economy.

II. LITERATURE REVIEW

A. *Innovation Management*

Innovation is a source of competitive advantage for a company and can stimulates economic growth [7], [8]. Furthermore, it is a generally accepted view that industrialization is founded on technological innovation. The

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concept of Innovation has been widely-researched and has been defined by various authors over the years. Drucker [9] defined innovation as an entrepreneurial tool that is specifically used to capitalize on change for a diverse business or service. The term innovation is a commercial consequent of an 'invention' or a technological advancement [10] – an invention that can be commercialised is an innovation. However, it also encompasses the implementation of new solutions, processes and procedures [11]. There are generally two types of innovations, namely, incremental or radical. Incremental innovations refer to innovations which may be viewed as an upgrade of an existing technology or product with the principal purpose of improving on its performance and making it more reliable. Radical innovations are breakthroughs that offer unique performance features and expand the capabilities of an existing innovation [12], [13]. Radical technologies are initially unappealing to mainstream customers when introduced to the market because they are viewed as inferior since they generally perform poorly on attributes valued by the mainstream clients early in their life cycle. However, over time the technology improves and eventually surpasses the existing technology, making it more appealing to the mainstream customers. Radical innovations are generally considered as being disruptive when they bring about massive transformations in the market and value networks.

Studies have shown that organizations that disregard disruptive technology do so at their own peril because they run the risk of being surpassed by the early adopters of the new technology, who tend to gain a competitive edge in the market over their competitors [13]. Companies that are able to remain innovative are said to possess 'innovativeness'. Wang and Wang and Ahmed [14] described 'innovativeness' as the propensity of a company to introduce new products or create new markets through strategic and competitive orientation. It is noteworthy that technology in itself may well not achieve success, except when it is properly and correctly implemented. Bower and Christensen [13] argue that established companies might not be able to successfully pursue disruptive technologies whilst trying to remain competitive in the current market. However, two (2) mitigation strategies are proposed to solve this problem – form a new business unit or establish an entire new company. Drucker [9] suggests that poor management of company resources is the major reason why companies are not able to achieve innovation success. Similarly, several theories or models have been developed over time to explain how new technologies are adopted or accepted and what factors influence the decision from both an end-user (individual) and organizational dimension. The technology acceptance model (TAM) introduced by Davis in 1985 is amongst the earliest and most widely applied models [15]. This model explains what drives an individual or end user to accept a new technology. The technology acceptance model suggests that perceived usefulness and ease of use are the two critical factors that determines user acceptance.

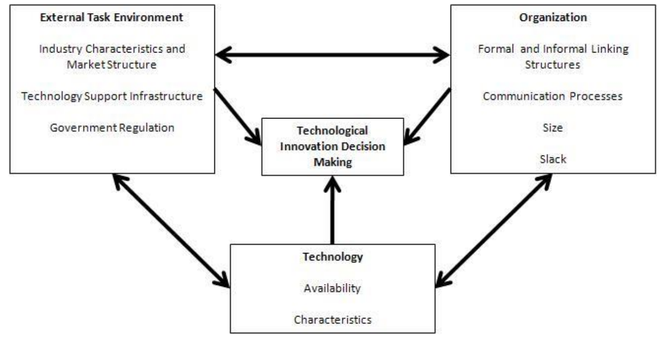

Fig. 1. The technology-organization-environment framework [16]

While TAM provides an understanding of what drive an individual to adopt new technology, theories such as the Technology, Organization and Environment (TOE) model provide an organizational perspective. Figure 1 shows the TOE Framework [16]. As can be seen from Figure 1, a company's decision to accept and implement a technological innovation is affected by its technological, organizational and environmental contexts. From the external environment context, government policy and regulation amongst others are vital and influential to innovation adoption.

B. Industry 4.0 Technologies

The fourth industrial revolution is characterized by a fusion of disruptive technologies that facilitate the complete automation of manufacturing facilities and the integration of a company's supply chain partners. These technologies encompass both software and hardware components [3]. Some of the major Industry 4.0 technology and concepts are discussed next.

1. *Big data*: refers to large and complex data sets that contain potentially valuable information. Amongst others, big data is generated by smart factories from various sources such as production equipment and associated business management software such as enterprise resource planning (ERP) and customer relationship management (CRM) systems. Big data analytics as the name implies is the process of evaluating big data to elicit trends and other actionable business insights which could ultimately benefit a company's operations, enhance sales and customer experience. Incorporating big data analytics into business decisions offers several prospects to gain a competitive advantage, enhance efficiency and productivity [17].

2. *Simulation*: is a method of executing a model to safely and efficiently solve practical problems in a virtual environment [18]. Simulation offers several benefits such as cost reduction and shorter development lead times. There are various reasons for simulations, such as prediction, performance, training, entertainment, education, proof, and theory discovery [19]. Simulations were traditionally used for developing

analytical and optimized solutions, but the trend has since shifted to supporting managerial decision making.

3. The Industrial *Internet of Things (IoT)*: is an extension or a next developmental phase of the Internet which was invented over 2 decades ago. IoT is a computing concept that describes the integration of different physical objects attached with sensors or actuators through the internet to remotely monitor and control specific equipment or activities [20]-[22]. These connected objects can collect and exchange large amounts of data in real time. The number of IoT connected devices is growing rapidly, over 23 billion devices are presently connected and that number is expected to rise to approximately 75 billion devices by 2025 [23]. IoT connected objects have vast capabilities and varied applications [24].

4. *Cloud*: is a computing concept aptly defined by the National Institute of Standards and Technology (NIST) as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction” [25]. The ‘cloud’ is a global network of remote servers that are interconnected via the internet and operate as a single ecosystem. These servers are designed to offer various services such as processing, data storage, management, etc. Such services are very cost effective and highly scalable because it is provided over the internet. There are five (5) essential characteristics of cloud services, namely, on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service [26]. Google drive, Microsoft one drive and Amazon web services (AWS) are common examples of cloud service offerings.

5. *Artificial intelligence (AI)*: is a cognitive science which covers several research areas, amongst others robotics, machine learning (ML) and image processing [27]. It embodies software (and presumably middle- and hardware) that can learn and perform tasks typically performed by humans that characteristically require a certain level of perception and reasoning. AI can learn and solve problems by making use of statistical data, which makes it an ideal system to control and manage facilities that produce large and diverse data in real time like in smart factories. Artificial Intelligence promises vast possibilities in virtually every industry. The technology is, however, still in its infancy and presently very expensive. The performance and success of artificial intelligence in industrial applications depend on the developer’s experience and sophistication of the computer system [27].

6. *Additive Manufacturing (AM)*: refers to an umbrella of technologies or processes capable of manufacturing an object from a three-dimensional computer model or design. The additive manufacturing process involves depositing layers of an appropriate feedstock sequentially until the final part is made [28]. Additive manufacturing or 3D printing technology offers several benefits such as a shorter product development cycle, facilitation of mass customization, and waste reduction [28]. Although AM still lags behind traditional manufacturing processes in terms of built speed, product accuracy and scalability, there has been a rapid increase in the rate of adoption of the technology by manufacturers. According to the Wohlers Report the overall market for Additive manufacturing continues to increase annually.

7. *Augmented Reality/Virtual Reality (AR/VR)*: are two different concepts that enhance human-machine interactions (HCIs) [29], [30]. Augmented Reality (AR) is an interactive technology that digitally inserts an object into the operator’s physical environment, while virtual reality (VR) effectively shuts out the user from the physical world. These technologies have several potential applications in different industries. For example, Data generated with VR technology can be used to develop training, communication, and interaction methods for different applications [30], [31].

8. *Blockchain (BC)*: became popular around 2008 with the introduction of bitcoin cryptocurrency in 2008 by Satoshi Nakamoto. Blockchain is generally described as a distributed database for storing and sharing securely. Blockchains can be classified into three categories, namely, public, private and permission BC [32]. Blockchain relies on peer-to-peer (PTP) systems to manage the integrity and flow of data. but the extent of possible applications is significantly larger. This technology has several applications besides managing cryptocurrency transactions [32]. For instance, it can be used to enhance transparency and security in logistics processes and supply chains.

C. Industry 4.0: History and Global initiatives

The concept of the fourth industrial revolution (industrie 4.0) originated in Germany at the Hanover Fair around 2011. The industrie 4.0 initiative which is a part of a much broader plan (high tech strategy 2020) was proposed to position German industries as market leaders in advanced manufacturing and producer of high tech products/services [33]. Subsequently, a Reference Architecture Model for Industry 4.0 (RAMI 4.0) was developed by some German institutions and Research Centres to support Industrie 4.0 initiatives. Rami 4.0 is a framework that defines the important aspect of industry 4.0 and supports organizations to identify future development opportunities [6]. Since the introduction of industrie 4.0 in Germany, other countries across the globe such as the United States (US), China and Japan have introduced similar initiatives albeit with different objectives to support the modernization of their industrial production sector.

In the US, government and private sector companies have introduced a number of 4IR initiatives. For example, the 'Advanced Manufacturing Partnership' (AMP) is a US government program aimed at facilitating innovation, talent acquisition, improving the business climate and ultimately improving their overall global competitiveness [34]. 'Start-up America' is another government strategy to inspire and promote entrepreneurship in the USA. Similarly, a consortium of US companies proposed an initiative called 'Industrial Internet' aimed at highlighting the importance of adopting cyber-physical systems in manufacturing and other sectors.

The 'Made in China 2025' strategy was introduced by the Chinese government in 2015 as part of a decade long strategic plan. This 4IR initiative involves the transformation of the Chinese industrial sector to become more competitive and increase the local production of core components [35]. The initiative is focused on several high technology industries such as aerospace, biotechnology and automotive industry. Presently, the government is aggressively investing in information and telecommunication infrastructure to fast track the transition to industry 4.0 and improve their technology readiness level.

The French government launched the 'La Nouvelle France Industrially' in 2013 to support revolutionising their industrial production base by identifying 34 sector-based priorities aimed at supporting businesses [36]. Subsequently, the 'industry of the future' project was launched, the initiative has five (5) key goals. These are: developing cutting edge technology, assisting businesses to adapt to new paradigms, capacity building, promoting the industry of the future, and strengthening European and international cooperation [37].

The Japanese government launched the "revitalization and robot strategy" with the goal of increasing productivity and robotization of the manufacturing and service industry by 2020. The 'Industrial Value Chain Initiative' was launched by Japanese companies to develop an industry 4.0 communications and software standard to facilitate a seamless connection for companies over the Internet and support collaboration among value chain partners. Other similar 4IR initiatives by the Mexican, Indian government are 'Crafting the Future' and 'Made in India' respectively.

D. Industry 4.0: South African perspective

The manufacturing sector is one of the major contributors and largest employers of both skilled and unskilled labour in many nations. The South-African Manufacturing sector contributed about 12% and 13% to the country's GDP in 2015 and 2016 respectively. However, it was the third worse performing sector in the first quarter of 2019 (falling by almost 8.8%). According to the global Competitiveness report published by the World Economic Forum, South-African global competitiveness has declined steadily, SA is presently ranked 67 out of 140 economies [38]. The South-African government recognizes that the fourth industrial revolution offers a unique opportunity to promote industrial development and ultimately improve on the lives of its citizenry. To this end, the government has been preparing for the 4IR through various agencies such as the Department of Trade and Industry (DTI); Department of Science and Technology (DST); the Council for Scientific and Industrial Research (CSIR) and the Department of Higher Education and Training (DHET) to develop policies and initiatives for the fourth industrial revolution. The Industrial Policy Action Plan (IPAP) and Future Production Technologies Initiative (IFPTI) are examples of initiatives that have been proposed [39]. Recently, the Future Industrial Production & Technologies (FIP&T) unit was established to explore and respond to the disruptive and challenging effects of industry 4.0. However, there is little or no evidence yet of any government level policies that have been passed to fund and support industry 4.0 in the country.

Several industries 4.0 maturity models or frameworks have been developed by various authors and organizations based on different dimensions [40]. For example, one such model evaluates the following four (4) factors: organization, information technology, performance, and lastly information connectivity maturity dimensions [39]. Another model surveys four (4) dimensions, namely, digital novice, vertical integrator, horizontal collaborator, and digital champion [39].

According to the world economic forum (WEF) readiness for the Future of Production report, all African countries assessed were categorized as 'nascent' which is suggestive of a very basic production structure and drivers of production. However, it is noteworthy that South Africa outperformed other African countries. A similar study conducted by Deloitte [41] to discover the readiness of South-African executives to the fourth industrial revolution revealed that a clear majority (96%) of the executives surveyed were not confident of their organizations' preparedness to fully exploit the possibilities associated with Industry 4.0. Dewa et al. [42] conducted a survey to assess the 4IR readiness level of South-African companies. The companies were assessed on the following criteria: Products and Services; Enabling Technologies; Manufacturing and Operations; Strategy and Organisation; Supply Chain Integration; and their Business Model. Their study revealed that the overall readiness level of South-African companies is to a large extent still within the foundation phase. Advanced analytics, cloud computing, mobile devices, and intelligent sensors, are some of the technologies that are increasingly being adopted by South-African manufacturers, while advanced technologies such as 3D printing and robotics are yet to adopted [42], [43].

The automotive sector appears to be the most vibrant industry leader in the adoption of disruptive technologies. This could be attributed to the automotive industry being run or characterized by Original Equipment manufacturers (OEMs) which have the necessary expertise and have, therefore, adopted 4IR technologies.

E. Fourth industrial revolution challenges

While Industry 4.0 is expected to offer extensive benefits, it will also create new situations and numerous challenges which encompass both technical, organizational, legal and societal issues [44]. Some of the notable challenges identified in the literature include lack of standardization; limited understanding of industry 4.0 concepts; inadequate broadband and IT infrastructure; insufficient education and training; lack of support from management and 4IR hesitance; cyber-security issues; and lack of investment [1], [44]. A survey conducted by Deloitte [43] to evaluate the opportunities and challenges for the South African manufacturing industry with respect to industry 4.0, revealed that the majority of the respondents identified infrastructure and talent acquisition to be the major challenges to industry 4.0 digital transformation. Some of the fundamental issues affecting South African manufacturers are briefly discussed next.

1. *Broadband and ICT Infrastructure*: South Africa arguably has one of the best fixed broadband and wireless infrastructures in Africa, however, access to fixed broadband like fibre is inaccessible to the majority of the population owing to its limited penetration and affordability. Mobile internet on the other hand has a higher penetration rate but data costs are more prohibitive. Furthermore, the current IT and industrial equipment in South African factories are old and include machines from different manufacturers – these systems are typical not 4IR environment compliant [43].

2. *Electricity*: Reliable and efficient electricity generation is vital for the effective adoption and implementation of fourth industrial revolution paradigms. It is common knowledge that manufacturing is the major consumer of electricity and a steady power supply is crucial for industrial development and sustainable growth of any nation. Stable electricity supply remains a challenge in the country. South Africa has an electricity installed capacity of about 51,309 megawatts (MW), most of which is derived from coal power stations [45]. The existing power generation infrastructure are dated, inefficient, and poorly maintained and as a result during times of increasing demand, load shedding is often implemented.

3. *Investment*: Lack of financial resources is one of the major barriers to adopting new technologies, particularly for small to medium scale enterprises (SMEs). Organizations will have to adapt or replace legacy IT infrastructure with modern technologies and may also need to change their current internal processes and business models to successfully adopt and implement the industry 4.0 concept – which may well require significant capital expenditure. Moreover, there is uncertainty around the economic benefit of 4IR investments. For instance, it is still uncertain how to estimate the potential return on investment (ROI) for implementing 4IR technology, hence it might be hard to postulate suitable arguments for the investment in such a system.

4. *Cybersecurity*: A major feature of Industry 4.0 is greater interconnectivity and data sharing. Naturally, such enhanced connectivity and availability of big data would significantly increase the risk of cyber-attacks and theft.

5. *Lack of skill*: The application of automation and robotics in manufacturing may well eliminate certain manufacturing jobs for humans, hence many would be out of a job with the increasing use of digital technologies. Yet, the said automation should create new types of careers that require a higher skill level and complexity [46]. According to a WEF report on "The Future of Jobs and Skills in Africa", African countries are ill-prepared for the imminent disruption to jobs and skills as a result of the industry 4.0, despite the continent boasting of a very young population [47]. In the South-African context, the country has for many years been experiencing massive skill shortages especially in high technology fields such as engineering and ICT. South Africa is presently ranked 67th globally in terms of human capital [38]. Automation and digitization of industries would further exacerbate the already high youth unemployment rate in the country if appropriate measures are not taken. Furthermore, as stated earlier, industry 4.0 implementation would require much more than the adoption of new technology but also changes in business processes and models. Deloitte [41], found that only two percent (2%) of South-African executives were confident of their capability to manage the industry 4.0 digital transformation.

6. *Mindset*: According to a study by the management consulting company Price Waterhouse Cooper (PWC) South African manufacturers do not exhibit a mindset that is fully geared towards industry 4.0 solutions [43]. Furthermore, a sizeable number of employees are, for various reasons resistant to new technologies or any kind of change in the workplace.

III. Conclusion

The fourth industrial revolution offers new and exciting possibilities in the transformation of traditional manufacturing facilities towards an unprecedented level of intelligence. Despite challenges, Industry 4.0 is presently making inroads into the South-African society. Advanced analytics, cloud computing and mobile devices are some of the technologies being adopted in various sectors, yet their adoption is still in its infancy. While the South-African government and businesses have acknowledged the potential impact of the impending digital revolution, supporting policies and regulations are yet to be introduced to facilitate innovation and the early adoption of industry 4.0 technologies. Infrastructure and human capital dimension are critical issues that need to be addressed to facilitate the digital transformation efforts. Consequently, increased investment in modern ICTs, and an efficient electricity infrastructure is imperative as well as introducing policies that would improve on the quality of education, training and innovation in the country. Furthermore, companies would need to invest in upskilling their workers and also prepare them for the robot revolution.

Future work in the 4^{th} IR may be pursued along a number of avenues: Since the overall technical readiness level of South African companies lies within the foundation phase, a 4IR maturity model for *developing* countries ought to be developed, similar to the various project management maturity models [48]. Also, since the 4IR landscape is so vast, several high-level and more detailed level frameworks for 4IR adoption in the various industries, sectors, etc. ought to be developed and validated over time.

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