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Original Research Article

Coherent Transition and Implementation Roadmap for Adoption of Industry 4.0 among SMEs in Africa

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Abstract: The industry 4.0 technology has been in existence and development for a while now and it has been fully implemented by the "big player" manufacturing companies in the world. This paper provides an assessment of the key technologies and the low state of implementation of this technological transformation by industries in Africa and especially the SMEs. Therefore, the article gives a guide and conceptual roadmap with necessary resources, practices and strategies for the middle African companies to implement industry 4.0 in their organization and reap the benefits of this industrial and technological revolution.

Keywords: Industry 4.0, automation, cyber-physical system, industrial internet of things, small medium enterprises.

I. INTRODUCTION

Industry 4.0, which may be abbreviated as I4.0, is the current transformation of manufacturing framework that utilizes digital information technology (IT) as well as innovative and agile operation technology (OT) in order to provide an inter-connected processes, applications and technology [1]. The connected factory model links various components in the manufacturing environment that include systems, machines, devices, processes, assets, services and people in order to provide a holistic, efficient, automated and information-rich manufacturing ecosystem. The resulting industrial smart-manufacturing architecture is sometimes referred to as "The Connected Factory".

The conceptual reference of the connected factory [2] is the Industrial Internet of Things (IIoT) that serves as a bridge in the integration of Business Intelligence Systems (BIS) as well as other advanced key technological Cyber-Physical System (CPS) [3, 4] advancements including robotics, cloud computing, artificial intelligence, big data analytics, simulation, system integration, embedded software systems with smart sensors. This integration creates a collaborative and intelligent connectivity of smart devices in a manufacturing environment commonly termed as an Industrial Control System (ICS).

The connected factory is growing courtesy to the increasing knowledge in the digitization of the manufacturing sector especially in the thematic areas of digital-to-physical conversion, human-machine interaction, analytics and intelligence, data, computational power and connectivity [5]. Leveraging on these technological opportunities, there are companies that have demonstrated and successfully implemented industry 4.0 in the manufacturing operations. These companies include Tesla Gigafactory in Nevada, United States, Bosch GmbH in Gerlingen Germany and Siemens PLC manufacturing plant in Amberg, Germany. Following the efficiency, digitization and optimization that industry 4.0 architecture brings in manufacturing processes, it has been implemented by the Small and Medium Enterprises (SMEs) [6] but the adoption is in lower scale especially in Africa. This therefore presents an opportunity for further exploitation of the full potential of the technologies.

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II. INDUSTRIAL REVOLUTION

The evolution and growth of manufacturing has gone through four phases i.e., phase 1 through to phase 4 and future progress will lead to an emergence of the fifth phase as shown in the figure [7, 8] below.

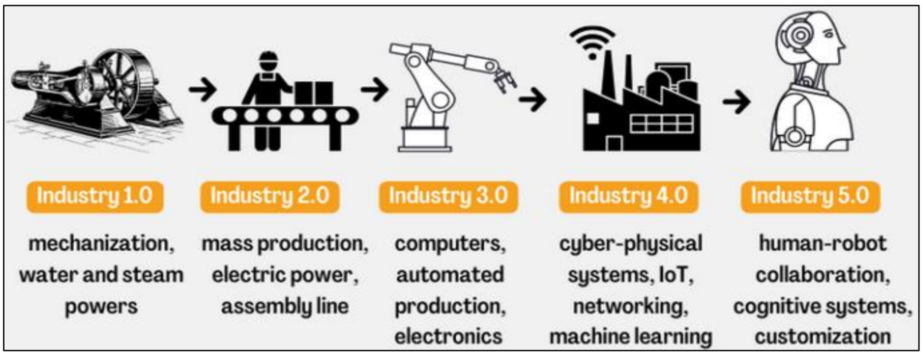

Fig 1: Evolution of Industrial Manufacturing

- Introduced as early as 1784, the pioneer industry 1.0 created a mechanized factory. This first industrial revolution was characterized by mechanization through the introduction of water and steam powered engine and machines.
- Later by 1870, the industry 2.0 brought about a mass factory. This second industrial revolution was characterized by assembly-manufacturing through the introduction of electricity, steel, internal combustion engine and mass production through assembly lines.
- Further development as of 1969, the industry 3.0 created the automated factory. This third industrial revolution was characterized by digital-manufacturing through the introduction of computers, electronics, robotics and Internet of Things (IoT).
- As of today, the industry 4.0 has developed a connected factory. This fourth industrial revolution is characterized by smart-manufacturing through the integration of Cyber-Physical Systems (CPS), IIoT-based ICS (Industrial Control Systems) and BIS (Business Information Systems) through advanced networking.
- Finally, a look into the future, the industry 5.0 will develop an intelligent factory. This fifth industrial revolution will be characterized by personalized manufacturing through cognitive cyber-physical systems and hyper-customization in order to achieve human-centric, resilient, collaborative and sustainable connected factory.

III. KEY TECHNOLOGIES OF INDUSTRY 4.0

Industry 4.0 technologies can be classified in four broad-based foundations [9] as follows: (i) connectivity, data, computational power, (ii) analysis and intelligence, (iii) human-machine interaction and (iv) advanced engineering as shown in the figure below.

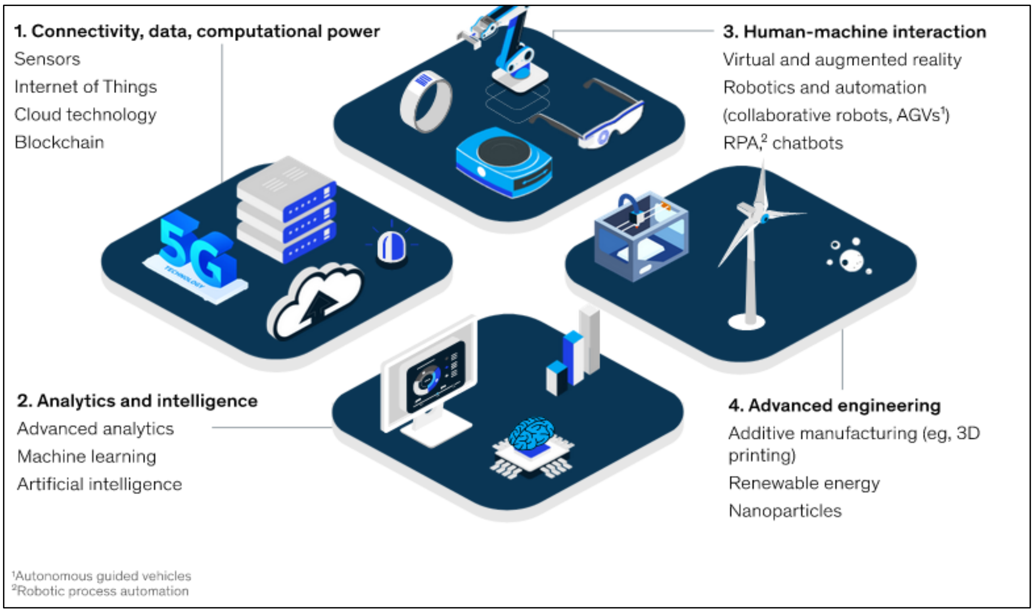

Fig 2: The four Classifications in Industry 4.0 Technologies.

Among the four broad-based foundational technologies, there are nine principal constituent technologies of the industry 4.0 architecture [3, 10-12] described as follows:

A. Industrial IoT (IIoT)

The IIoT technology is basically the utilization of networking technology, smart sensors and embedded systems in industry 4.0 that connects to the internet in order for machines to send, receive and process data. This internet connected system can perform decentralized and remote multidirectional communication and computing of industrial processes.

B. Autonomous Robots

Automation in industry 4.0 relies on advanced robots and machinery that are programmed to operate autonomously with minimal human supervision. Mobile robots, sometimes referred to as Automated Guided Vehicles (AGVs) can be utilized in an efficient and convenient factory floor transportation. Future innovations will integrate collaborative robots (cobots) built with intelligent communication and coordination in fulfilling industrial processes.

C. Additive Manufacturing

The additive manufacturing is based on 3D printing and modelling in order to provide batch construction and transformation of prototype to an actual production. The AM follows digital 3D design data building in layers by depositing materials to create a compact and complex design.

D. Cloud Computing

High performance cloud computing offers IT services over a network based on remote servers that store, share, manage and process data for reliable and scalable interconnectivity as well as quick and real-time execution of industrial processes. The cloud computing services are data-driven since they can be scaled up or down depending on the demand of the functional deployment.

E. Big Data & Analytics

As a technology in industry 4.0, big data and analytics utilizes advanced statistical methods and measures in order to monitor real-time performance on data-sets. Based on the results, the system can then be able to tweak its parameters, improve industrial processed and determine further actions and decision-making support for optimum productivity. Further incorporation of data intelligent systems of Artificial Intelligence (AI) and Machine Learning (ML) in the analytics can provide real-time optimization of the industrial processes.

F. Simulation

Visual aids, utilities and software can be used to imitate the complex designs and operational framework of the industrial system. Simulation also can provide virtual models for human resources support through training. Through digital twins, simulation using a digital copy of the industrial system that provides analysis, planning, testing and development of industrial components and systems.

G. Cybersecurity

Cybersecurity provides a preventive protection layer for sensitive data and information that is stored in the cloud and also safeguard during transfer between IIoT system components.

H. System Integration

The horizontal and vertical system integration in the industry 4.0 technology provides a consistent and fitting architecture for further addition and integration of more cyber-physical systems as well as business intelligence systems without compromising the reliability and networking of the existing ecosystem. The smooth implementation of new and novel technologies can enhance the complete automation of the supply value chain.

I. Augmented Reality

By utilizing Augmented Reality (AR) in industry 4.0, AR provides a digital interaction and information by integrating real-time and real-world human experience with the industrial system. AR interactivity can help industrial systems in terms of design, development, maintenance and logistics as well as product trials, promotions and marketing.

IV. SME IMPLEMENTATION OF INDUSTRY 4.0

The top three leading countries globally in the implementation of the industry 4.0 can be attributed to 2015 research by McKinsey & Company [13]. The survey reported 83%, 57% and 34% preparedness for the United States, Germany and Japan respectively.

A. Requirements

Research by [13, 14], has conducted a survey to determine the readiness of organizations to implement the industry 4.0. The results of the survey have indicated that the implementation preparedness varies according to the nature of the industry and those companies in software industry, heavy/industrial machinery, discrete manufacturing, process industry and logistics companies have the readiness percentage of 65%, 63%, 59%, 51% and 49% respectively as shown in the figure.

1) Assessment: Prior to the implementation of industry 4.0 in the SME, there are questions that should be answered to determine the readiness of adopting industry 4.0. The main questions that should inform the criteria for assessment of readiness for industry 4.0 adoption in the SMEs include the following four principles:

a) *Interoperability:* The question that should be asked is whether the machines, devices, systems and people can connect and communicate with each other.
b) *Information Transparency:* An inquiry should be to determine whether the systems create virtual replica of physical world based on the sensor data.
c) *Decentralized Decision-Making:* An investigation should be made to ascertain that the cyber-physical systems make simple decisions and can become fully autonomous.
d) *Technical Assistance: A* general assessment of the systems to support humans in making decisions, solving problems and assisting with tasks should be done

2) Adoption: *Based on the identification of the requirements for the implementation of industry 4.0 in SME, its adoption may be achieved in three different methodologies [3]:*
Accelerated adoption: Best for SMEs with highly-demanding industrial operations with digital capabilities and technical infrastructure for a rapid integration of industry 4 into the organization. Such SMEs include health industries and fintech companies
a) *Differential adoption:* Ideal for SMEs that have well-established and existing technological resources that provide a phased and periodical integration of the industry 4.0 in their company. Examples may include the process industry and logistics companies.
b) *Deferred adoption:* Practical for SMEs whose industry 4.0 implementation is capital intensive with long-term or indeterminate return on investment (ROI). Such enterprises may include complex industrial automations, nanotechnology and blockchain industry

B. Transformation

The process of implementation of the industry 4.0 in the industrial operations requires a transformation between various architecture [15] and there are protocols are required in order to allow for communication and data transfer. Such industry-standard protocols for I4.0 system transformation [16-18] are listed in the Table I:

Table I: I4.0 Transformation PROTOCOLS

Protocol	Architecture
SECS/GEM	The SEMI Equipment Communications Standard / Generic Equipment Model (SECS/GEM) standard protocol provides communication interface between sensors, devices and systems (such as ERP, MES and PLM)
OPC	The Open Platform Communication (OPC) standard protocol utilizes the Microsoft Object Linking & Embedding (OLE) to offer communication interface between clients (PLCs) and servers (MES) and therefore provides a middleware communication for HMI and SCADA.
OPC UA	The Open Platform Communications Unified Architecture (OPC UA) standard is utilized as an industrial data model for automation devices and systems
UNS	The Unified Namespace (UNS) architecture model provides a real-time processing and transfer framework of standardized data between nodes of an IIoT system
SOA	The Service Oriented Architecture (SOA) serves as a software development model that interface between different language platforms and has the following classes Java Message Service (JMS), Advanced Message Queuing Protocol (AMQP), Message Queue Telemetry Transport (MQTT), Extensible Messaging and Presence Protocol (XMPP)

C. Integration

1) *IIoT Integration:* An Industrial Internet of Things (IIoT) integration in a connected factory has IIoT-enabled smart sensors, actuators, devices, appliances or systems that utilize various internet connection options such as WiFi, 5G, 4G/LTE, bluetooth etc. in order to connect to the cloud computing platform. A schematic overview of an Industrial IoT platform is shown in the figure [19].

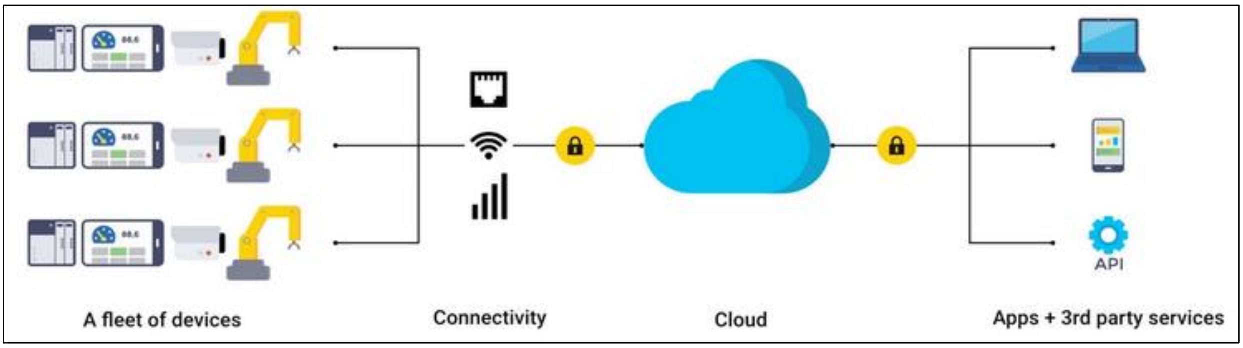

Fig 3: A schematic overview of an industrial IOT platform

2) CPS Integration: The Cyber Physical System (CPS) integration, as shown in the figure below [20], is basically the linking of the IIoT architecture together with various modules that include gateways, machine learning, big-data warehouse, data analytics among others.

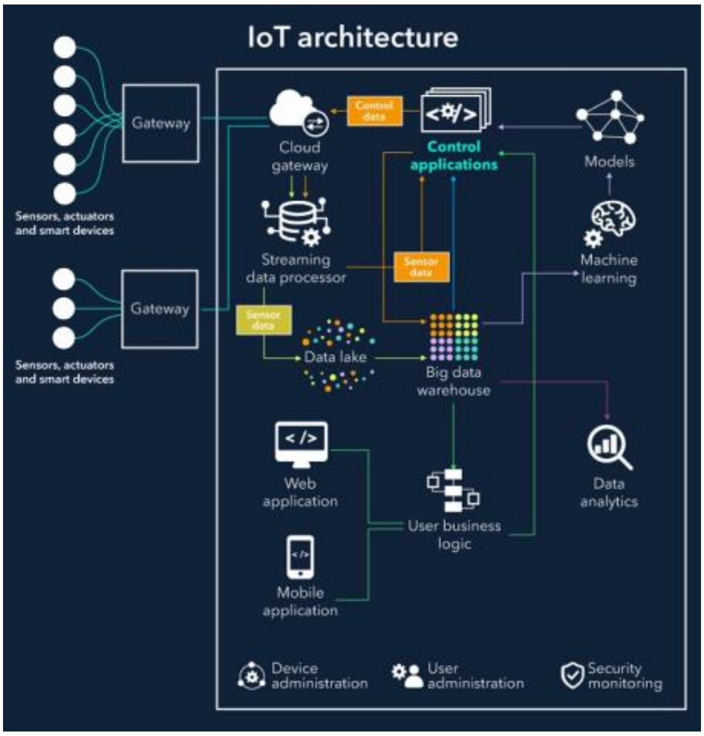

Fig 4: IOT Archiecture [20]

3) *BIS Integration:* The business intelligent systems (BIS) integration includes various enterprise systems that provides support services and management of the industry 4.0 enabled SMEs. The most common BIS systems [16, 21] that the integration should focus on are: Enterprise Resource Planning (ERP), Product Lifecycle Management (PLM), Customer Relationship Management (CRM), Master Data Management (MDM) and Supply Chain Management (SCM).

D. Case Studies

1) *AWS-Based Industrial IoT Platform:* The AWS cloud computing platform IIoT integration utilizes AWS Industrial Machine Connectivity (IMC) architecture to provide an interface between the IIoT-enabled systems and/or devices with the AWS cloud [23]. The IMC relies on both the OPC-UA and the MQTT architecture to offer communication interface between the smart devices and the cloud computing platform.

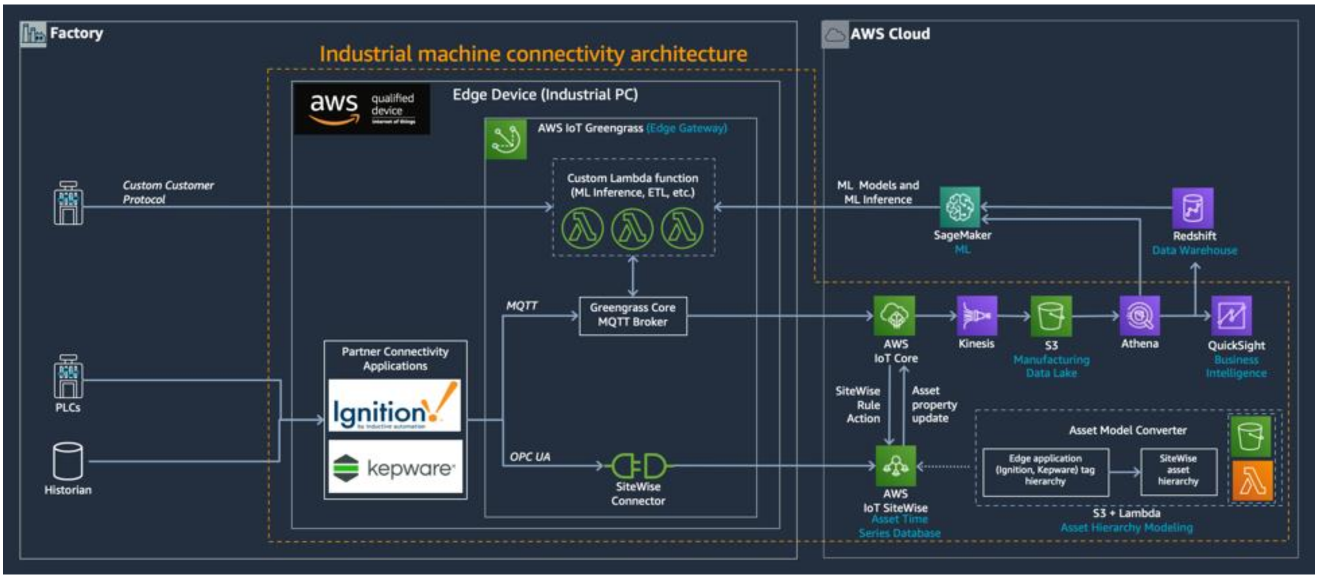

Fig 5: Representation of Industrial IoT Platform with AWS as in [23]

2) *Azure-Based Industrial IoT Platform:* The Microsoft Azure cloud computing IIoT integration [22] utilizes the industrial IoT edge installer platform provide an architecture of the connected factory through the OPC-UA architecture for communication interfacing between the IIoT smart devices and the cloud computing platform as shown by the data flow diagram in figure below.

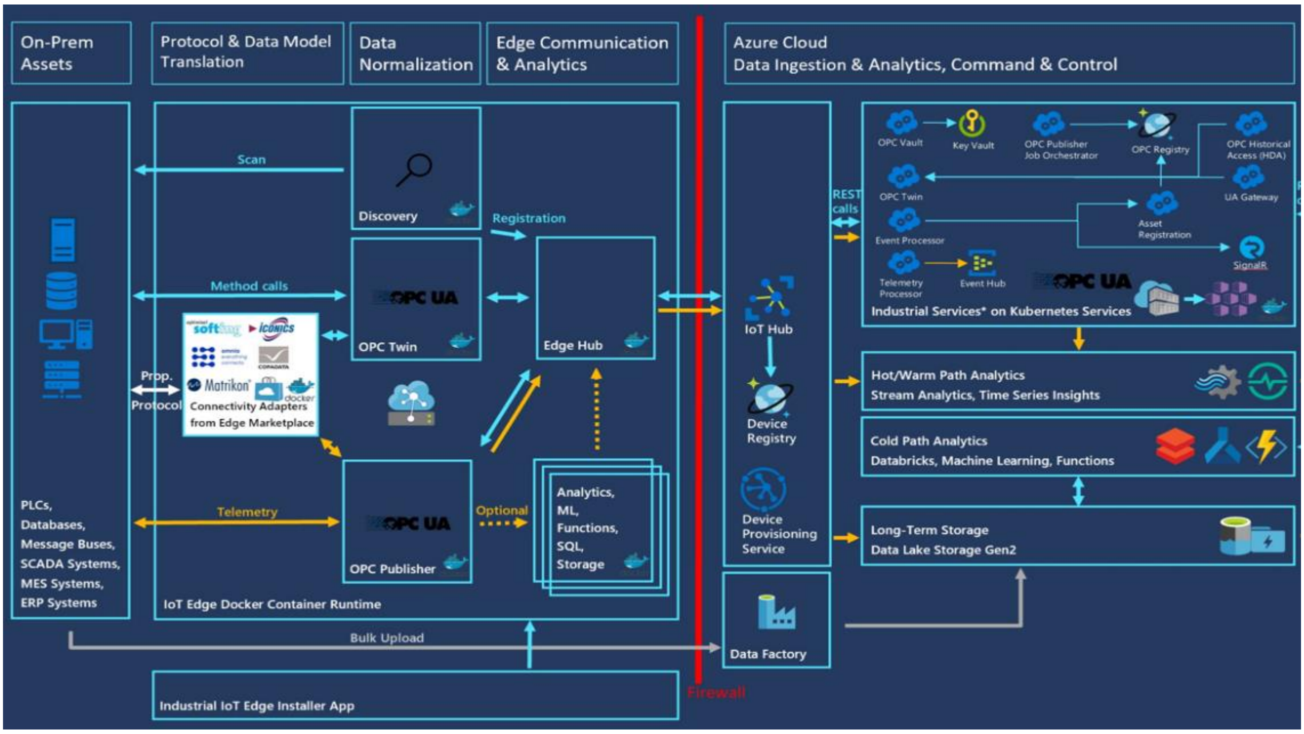

Fig 6: Azure-based Industrial IoT platform

V. BENEFITS AND CHALLENGES

A. Benefits

There are a variety positive impacts [1] of the I4.0 for SMEs as outlined below:

1. *High Profits:* the connected factory guarantees high precision and fully automated industrial processed with improved efficiency in the entire production workflow. This results to high productivity due to optimal manufacturing that has high returns on investment and hence high profits.
2. *Reduced Cost:* the integration industry 4.0 digital technologies in industrial processes of an SME can provide better management of resources and assets through predicative maintenance for machinery and equipment, low production downtime and minimal production wastes. The end result is the reduction of overall production and operation costs.
3. *Predictive Maintenance:* the integration of I4.0 real-time proactive maintenance of industrial operations by performing AI-powered Root Cause Analysis (RCA) to identify possible systems failures aimed at reducing the MTTR (Mean Time to Repair). This can help deliver minimal wastages and high productivity.
4. *Improved Agility:* the high efficiency that industry 4.0 brings to an production process of an SMEs can further improve the quality of products, enhance worker safety and contribute towards environmental sustainability.

B. Challenges

There are few aspects of the industry 4.0 that has not been fully exploited in order to realize the full potential in manufacturing among SMEs. This includes (1) standardization, (2) security threats from increasing cyber-attacks in a fully networked manufacturing which compromise data privacy due to breach of the access to sensitive enterprise data [15] (3) research and development due to disparate and overwhelming pools of data (4) deployment burden resulting from employee resistance.

VI. CONCLUSION

The implementation of industry by SMEs in Africa can be propelled by factors like the growing industrial networking and digitization. Though the utilization of the current high-tech innovations, industrial processes can be optimized for deliver better RCA of the industrial system in order to increase the reliability of operations, increase efficiency and agility in production. Therefore, investing in the connected factory can guarantee higher ROI as well as future industrial sustainability.

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