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# Towards Flexible Manufacturing Systems in Africa (A review)

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**Abstract**

*In comparison to the rest of the world, Africa has a low rate of adoption of innovative manufacturing technologies and concepts such as flexible manufacturing systems (FMS). Studies show that advanced manufacturing technologies and concepts boost a production firm's total performance, which is why the African manufacturing industry should adopt these technologies and concepts in order to quickly be industrialized. The goal of this research is to investigate manufacturing and its influence in Africa, as well as the adoption and state-of-the-art of flexible manufacturing in Africa, but also the challenges and research possibilities that come with adopting modern manufacturing technologies. Based on the literature research, in comparison to the rest of the world, the adoption of flexible manufacturing systems in the African manufacturing industry is quite low. The importance of African manufacturing enterprises adopting FMS and other modern manufacturing technologies and concepts, as well as research potential for smart FMS, are discussed in this study. This study also reveals that if a large percentage of African manufacturing enterprises implement FMS and advanced manufacturing technologies (AMT), the continent's manufacturing profile will be transformed in unprecedented ways.*

**Keywords:** Flexible manufacturing systems, African manufacturing industry, Advanced manufacturing.

## 1.0 INTRODUCTION

In term of quality, flexibility, efficiency and cost-effective production of goods services, African manufacturing sector face several problems. As result, Growth in the industry has slowed, even though other regions of the world, such as Europe, Asia, and America, are far ahead. Technological innovations in manufacturing are the task of next-generation industries, where there is massive demand and substantial profit to be made[1]. Automation, robotics, computer numerically controlled (CNC) machines, and other modern concepts, such as flexible manufacturing systems(FMS), are motivating industries to achieve these Technological capabilities[2]. The introduction of flexible manufacturing systems in African manufacturing industries will not only increase quality, productivity and profits but will transform the sector into a much better version.

FMS is defined as "an integrated, computer-controlled complex structure of automated material-handling systems and numerically controlled (NC) machine tools that can process moderate volumes of a variety of part types at the same time." A system that can produce a wide range of items by combining numerous programmable machine tools linked by an automated material handling system.[3].

Inventory reduction and market response time, flexibility to adapt to market changes, lowering the cost of products and services, and other factors made it almost mandatory for many businesses to switch to flexible manufacturing systems (FMSs). Switching to FMSs increases the chances of meeting the aforementioned requirement while producing consistent results[4]. The implementation of FMS is expensive however, the benefits it promises, such as "overall increase in productivity, improved quality and flexibility, and reduced production time and cost," are enormous. The adoption of FMS is also an opportunity for the manufacturing industry to make use of advanced technologies that make the production process easy and increase the overall output.

### *1.1 Theory of Flexible Manufacturing Systems*

Flexible manufacturing systems are modern manufacturing concepts that consist of several machines dedicated to producing various components in the shortest amount of time possible. It is called flexible because it is extremely adaptable in terms of machine functionality, process sequences, product, production, and development [5]. The design of a flexible manufacturing system (FMS) is a high-investment project with the goal of combining

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production flexibility and productivity[6]. In other to justify the implementation of FMS with its initial high investment cost, different researchers have investigated the viability of implementing it from several studies. For instance, Dolage and Sade [7]investigated the impact of the adoption of flexible manufacturing technology(FMT) on the price-cost margin of the Malaysian manufacturing industry and discover enough evidence to conclude that FMT has a direct and moderately significant correlation with price-cost margin.

Furthermore, Hammel [8] explored three key benefits of a modern flexible manufacturing system and discovers that FMS provides increased efficiency, production flexibility, and is fully integrated. The author observed that a modern FMS serves as a link between the departments of planning, engineering, and programming and the manufacturing shop floor. More so, it provides complete transparency on every single process step throughout the entire value chain. In a comprehensive analysis and future trend of a simulation study on FMS scheduling, Chan and Chan[9] conducted that artificial intelligence methods will be dominating in future research. Artificial intelligence is the buzzword of the day when it comes to enhancing the industrial business. Pandey and Sharma[4] investigated the performance evaluation of flexible manufacturing systems in manufacturing industries and discovered that applying FMS results in improved output and decreased station idle time. Furthermore, because comparable equipment may share components, FMS reduce carryover effects when a station are halted and saves the expense of maintaining spare part stokes.

Mishra et al [10]researched on the non-traditional optimization techniques of scheduling in FMS and made the following six conclusions:

I. Mathematical models with fewer constraints and greater efficiency must be developed
II. Because most researchers have only used a single objective, multi objective FJSSP (flexible job shop scheduling problem) must be investigated.
III. It is also necessary to simulate large-scale real-world FMS problems with fewer assumptions to solve them.
IV. As the problem grows so does its complexity. Meta heuristics produce good results in such situations.
V. The combination of new Meta heuristics guarantees a very good pare to the optimal solution in a reasonable computational time.
VI. The research can be expanded to include simultaneous part scheduling and automated guided vehicles.

Tamimi et al. [11] analyzed the performance measures of a flexible manufacturing system and found that the simulation models are easy to analyze the complex flexible manufacturing system. Base on the articles reviewed, there has been a significant amount of research done on flexible manufacturing systems and their impact on the manufacturing sector. In terms of the use of modern technologies and concepts, African manufacturing industries are still young and growing. In this study, Manufacturing and its impact in Africa, the adoption and state of the art of flexible manufacturing in Africa, and finally challenges and research opportunities in the African manufacturing industry are reviewed. Subsequently, the research recommends strategies to promote the growth and development of FMS on the continent.

## 2.0 MANUFACTURING IN AFRICA

Africa is a continent brimming with growth opportunities. A strong manufacturing sector is one of the engines driving African development [12]. The continent is reached in natural resources and agriculture products and yet it is the poorest continent on the planet. If African countries promote export manufacturing instead of raw materials, it will not only change the lives of its citizens, it will transform the entire continent.

Africa's large share of the global population (17%)[13] combined with its small share of global GDP (3%) implies that the average global GDP per capita is nearly six times higher than Africa's. In terms of manufacturing, Africa accounts for about 2% of global manufacturing value-added (MVA); the average global MVA per capita is nearly nine times that of Africa[13]

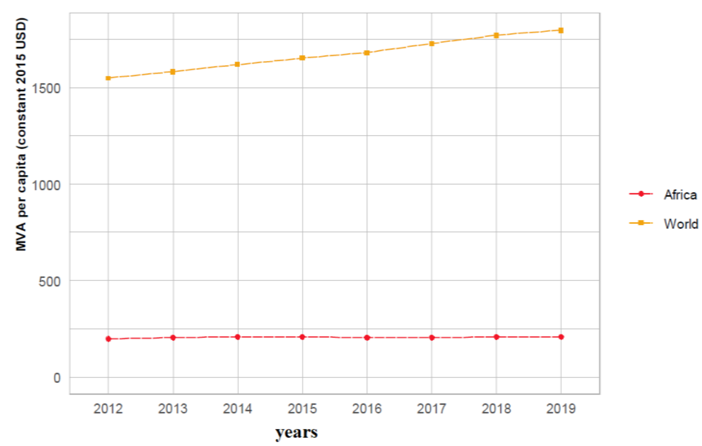



**Figure 1.** Manufacturing value added per capita in Africa and the world, 2012–2019 (*Source: UNIDO, MVA database 2020*)

Fig 1. This shows that the value-added per capita by manufacturing in Africa is very low compare to the world. In other to close this gap, policymakers should formulate feasible and sustainable models for the manufacturing sector that can compete in the global market. Everywhere, industrialization has been associated with economic growth and development. However, the link appears to be weak in Africa. Manufacturing's GDP share was around 10% in 2015, and as table (1) shows, the sector has grown more slowly than the economy as a whole in every period since the 1960s[14].

**Table 1.** The share of manufacturing in GDP 1960-2012

| S/N | Growth | 1961-1979 | 1980-1999 | 2000-2012 |
|---|---|---|---|---|
| 1 | GDP | 4.9 | 2.4 | 4.9 |
| 2 | Agriculture | 3.3 | 3.3 | 3.6 |
| 3 | Industry | 6.1 | 1.5 | 5.2 |
| 4 | Manufacturing* | 4.4 | 1.7 | 3.1 |
| 5 | Services | 4.5 | 3.0 | 5.6 |

**Source:** UNECA, 2015: 47

The fact that African economies have a very weak industrial structure in terms of both the number of firms and their average size is an important feature. Another fascinating aspect of African manufacturing is that domestic firms have limited technological capabilities and are embedded in fragmented learning and innovation systems[15]. Countries like Kenya, Nigeria, Ghana, South Africa, Tanzania, Rwanda, Uganda, etc. have developed industrial policies that can promote and sustain a vibrant diverse manufacturing sector for Africa. The manufacturing industry has been identified as the key driver for economic growth and development in Kenya's Vision 2030 due to its enormous potential for job and wealth creation, as well as its high potential for achieving the Millennium Development Goals (MDG). Kenya aspires to be a middle-income, rapidly industrializing, globally competitive country, and an effective industrial policy framework is required to drive this process[16].

In *Nigeria*, various industrial policies/industrialization strategies such as import substitution approach, export promotion strategy, and foreign private investment-led industrialization, as well as policy reform measures such as indigenization policy, structural adjustment program, and so on, have been formulated and implemented over the years in an attempt to facilitate industrialization in the country[17]. The importance of industrial development to the development of an economy cannot be overstated. In light of this, Ghana has developed the One District One Factory Policy (1D1FP), which aims to establish at least one factory in each political district based on raw material availability[18]. The South African National Industrial Policy Framework (NIPF) was launched in 2007 to serve as a point of reference for the development of rolling Industrial Policy Action Plans in particular, as well as economic and sector policy across government as a whole. The NIPF was created in the context of South Africa's Accelerated and Shared Growth Initiative, which was led by the Presidency. With a strong emphasis on manufacturing as a key driver of balanced development[19]. Tanzania's new industrialization era is marked by the formulation and implementation of the Sustainable Industrial Development Policy 2020 (SIDP), which aims to create an industrial sector geared toward human development and job creation, economic transformation for economic growth and sustainable development, environmental sustainability, and equitable development[20]. Rwanda's 2011 policy was developed to help Rwanda achieve its goal of becoming a middle-income country by 2010, in part through deliberate structural transformation and export promotion [21]. The vision of *Uganda's* industrial policy is to transform the industrial sector into a modern, competitive, and dynamic sector that is fully integrated into the domestic, regional, and global economies [22].

All of these African countries' policies have one main goal in common: "industrialization," which is a driver of economic growth. When some of these policy frameworks are examined, they appear promising, but the big question is why aren't they working for Africa? There is a need to investigate why these policies are failing in these countries. There is still significant room for growth and expansion in Africa's manufacturing sector, and as labor costs rise in other developing regions, the world bank has suggested that these manufacturing jobs may migrate to Africa in the coming decades[23]. If this is the case, African governments should create a favorable environment for this shift by establishing sustainable policies, adequate industrial infrastructure, and adequate investment in the sector.

### *2.1 State of the art of flexible manufacturing in Africa*

There has been a lot of research and development globally in the area of flexible manufacturing and this gives rise to a lot of improvement in the manufacturing industry. Studies[24] show that investing in long-term flexible manufacturing systems results in the improvement of the overall manufacturing process. In order to track progress in the sector, it is necessary to assess the state of the art of the FMS as well as its impact on the sector.

*2.1.1. The state of FMS globally*

There has been an exponential growth in the use of technology and technology-related knowledge in manufacturing and flexible manufacturing system is not an exception. FMS has also its share in these growths and developments. A flexible manufacturing system may consist of a network of interconnected processing workstations with computer terminals that handle the entire product creation process, from loading/unloading functions to machining and assembly to storing to quality testing and data processing. The system can be programmed to run a batch of one set of products in a specific quantity, followed by an automatic switch to another set of products in a different quantity[25]. To achieve these superior manufacturing benefits, some basic FMS components must be established. The fundamental structure of FMS is made up of four (4) core components. They are as follows: (1) workstations; (2) material handling and storage systems; (3) computer systems; and (4) managers and operators[26]. Although many other additional components can be included, these are the primary components to which everything is connected.

*2.1.1.1 Workstations*

These workstations are typically computer numerical control (CNC) machine tools that execute machining operations on families of parts in modern applications. Other types of processing equipment, such as inspection stations, assembly lines, and sheet metal presses, are being used to create flexible manufacturing systems. [27]. The various workstations are:

- Machining centers
- Load and unload stations
- Assembly work stations
- Inspection stations
- Forging stations
- Sheet metal processing, etc.

**Note:** Workstations are not necessarily limited to these, and there are many other types of workstations that can be added to the system.

*2.1.1.2 Material handling and storage systems*

The material handling system feeds material to the machines to ensure smooth operation. This system can be made up of any number of conveyors or filament spools that can be rearranged and adjusted to meet the needs of the production. Material handling accounts for 25% of all employees in a typical manufacturing plant, 55% of total company space, 87 percent of production time, and 15%–70% of total product cost[28]. The material handling and storage system in an FMS's function is to move work parts randomly and independently from station to station, handle a variety of part configurations, temporal storage, and accommodate convenient access for loading and unloading of parts while being compatible with computer control. Equipment for material handling and storage systems includes:

- Conveyors
- Industrial robots
- Automated guided vehicles (AGV)
- Temporal storage unit

The use of this equipment is determined by the layout of the FMS. One of the following layout configurations may be used for the layout:

- Inline layout
- Loop layout
- Open field
- Ladder layout
- Robot centred layout

*2.1.1.3 Computer systems in FMS*

The FMS is comprised of a distributed computer system that communicates with workstations, a material handling system, and other devices. A typical FMS computer system consists of the main computer as well as microcomputers that control the individual machines and other components. To ensure that the system runs smoothly, the central computer coordinates the activity of the components. The FMS computer control system performs the following functions in the categories listed below:

- Workstation command and control, as well as instruction distribution to workstations
- Production control
- Traffic and transport control
- Work piece monitoring
- Tools and tools location control
- Tools life monitoring
- Performance monitoring, reporting, and system diagnostics

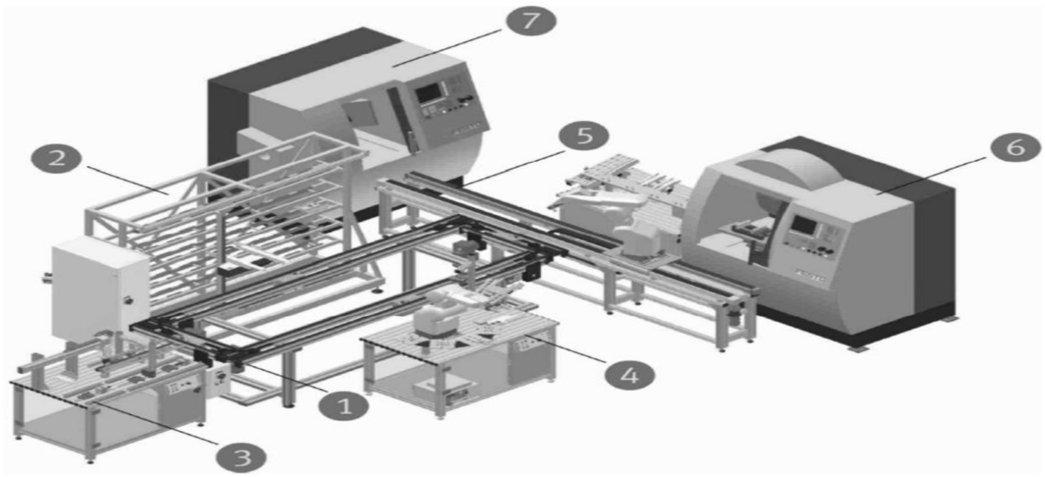
**Note:** Depending on the complexity of the system and the desired objectives, modern FMS may have more system control.

*2.1.1.4 Operators and Managers*

Although the number of people employed at FMS facilities is limited in comparison to conventional manufacturing plants, some people are required to operate and manage the facilities.

Personnel is needed to handle FMS operations such as feeding raw work parts into the system and unloading finished parts from the system, in some cases changing and setting tools, repairing and maintaining the equipment, designing and CNC part programming, PLC programming, and computer system operation, and overall management of the FMS system. It should be noted that the operation of FMS necessitates the use of a skilled individual in modern technologies.

The four main core components discussed in this section are common to all types of FMS irrespective of the type of product they manufacture.




1. Conveyor
2. Storage
3. Pallet Handling and Quality Station
4. Robot Vision and Assembly Station
5. Robot Feeder of Machine Tools
6. CNC Lathe
7. CNC Milling Machine

***Figure 2.*** *Flexible manufacturing systems structure [29]*

Flexible manufacturing systems and computer integrated manufacturing (CIM) systems are similar but the difference is that FMS allows for the manufacture of several goods within the parameters set out in the system's initial design. The given production orders and strategies can change the various product variants. On the other hand, CIM which is developed by connecting islands of automation into a distributed processing system, CIM is concerned with providing computer assistance, control, and high levels of integrated automation at all levels of the manufacturing (and other) industries[30]

***Figure 3****. CIM Lab In ecolenationalesuperieurepolytechnique, Cameroon*

According to intelitek a world-leading producer and supplier of technical training solutions and also suppliers of FMS lab equipment, “A machine tending station, which typically integrates a robotic arm with mobility components such as a slide base, materials handling devices, and a machine such as a CNC machine. Each FMS setup or cell is intended to carry out a specific task in the manufacturing process. Intelitek CNC machining and turning centers, SCORBOT and MotoMan robots, advanced simulation, automation, programming, and control software, and curriculum are all part of our FMS product line"[31]. There are several suppliers of FMS laboratory equipment for educational purposes including Intelitek in the US, Naugra Export and Astras scientific in India, Dolang Technology Equipment in China, etc. of which the FMS features and setup may be different depending on the customer preferences but the core components are all the same.

### 2.1.2 *The benefits realized by some firms that implement the FMS concept.*

The concept of flexible manufacturing systems is not new in the manufacturing sector. The system is used to manufacture parts and products for a wide range of industries, particularly those that rely on high-quality metal-based elements, such as aerospace, medical, military, construction, and mining. They are also employed in industries that have direct contact with consumers, such as automobiles and electronics. Several manufacturing industries recognized the benefits, advantages, and the increase in return on investment promised by flexible manufacturing systems which leads them to the implementation of the concept in their manufacturing plants. Companies like Siemens, Ford, Prince Industries, Toyota Motor Corp, Mazda, and Premium AEROTEC, etc.

#### *2.1.2.1 Siemens*

Siemens' digital twin of the product, manufacturing process, and production performance enables flexible manufacturing, reduces time to market and cost, improves quality, and boosts productivity across all levels of a business organization.

#### *2.1.2.2 Prince Industries*

The company desired to grow by utilizing a flexible manufacturing system to reduce setups and deliver a completed part from the design to the production stage in a shorter period. The company then invested in five flexible manufacturing concepts, and they gained the following benefits[32]:

- Around the clock, seven days a week, Prince runs 24 full pallets of work. There has never been a part rejection, and all scrap has been eliminated. Every component is removed from the cell and delivered to the customer.
- Productivity per hour has increased by 50%, allowing Prince to go from producing three to four parts per hour on stand-alone machines to producing six parts per hour.
- If the company gets a customer order, it can acquire material the same day, provide a single setup, and then begin production immediately. Furthermore, customers with lower volume jobs pay the same part cost as they did for mass production runs.
- The standards has improved. Prince can handle three-dimensional parts with tight tolerances in a variety of positions, including diameter tolerances of 0.00052 inches. The company estimates that tool changes alone save it 20 to 30 percent in cycle time. It operates a flexible manufacturing system 24 hours a day and has never had a rejected part pass through its machines.

#### *2.1.2.3 Ford*

Manufacturers are looking to introduce more flexibility in their production and are re-evaluating their strategies for in sourcing and outsourcing to avoid having to re-fit factories more frequently and to make upgrade work count, according to experts from Volkswagen, Ford, Renishaw, and Atlas Copco at last week's AMS Live stream on electrifying production[33].

#### *2.1.2.4 Mazda*

Mazda Motor Organization's current success can be measured by its flexible manufacturing system, which allows product developers and manufacturing to make quick product modifications when the market demands change[34].

#### *2.1.2.5 Premium AEROTEC*

According to Premium AEROTEC, a German aerospace manufacturing company, flexible manufacturing systems can reduce running time by 15%. "In addition to their dependability, the ECOSPEED machines' high overall dynamism won us over," says Christian Welter, Head of Large-Part Production at Premium AEROTEC. "This is why we chose two ECOSPEED F2040 machines as our most recent investment, which have been linked to form a flexible manufacturing system [35]."

Flexible manufacturing turns out to be a good concept for return of investment and the overall improvement of the manufacturing industry. With all these successes achieved by FMS, there is still room for improvement to reach the highest level of flexibility in manufacturing. Unfortunately, there has not been much research and development in FMS in Africa. Since the manufacturing industry of Africa is below average compare to the rest of the world, the use of advanced technologies in manufacturing is also below average and this makes it very difficult to research FMS in Africa since the available data on the subject is very limited.

### *2.2 FMS in the African context*

Most of the manufacturing firms in Africa still use the conventional method and model of manufacturing and these are some of the reasons why the sector is continuously declining in the continent. There is a growing consensus [36−37] that the use of advanced technologies in manufacturing improves firm performance, which is supported by the accomplishments of firms that use these advanced technologies in their manufacturing plants. The majority, if not all, of the success stories involving flexible manufacturing systems, have occurred outside of Africa. The technologies used in flexible manufacturing systems are new and expensive to implement and maintain for most African manufacturing companies. This makes it difficult to locate a firm that uses the concept, making it even more difficult to research FMS. Notwithstanding, there have been some developments in the area of research and the use of modern technologies in Africa for example, Google recently established its first Africa Artificial Intelligence laboratory in Ghana [38], Andela is a company that assembles high-performing engineering teams from Africa's most talented software developers [39] with offices in Nigeria, Kenya, and Uganda. In comparison to the rest of the world, the African continent's current adoption and impact of Industry 4.0 remains low. However, it is a topic that is becoming more widely recognized and discussed by industry leaders and policymakers [40].

Compared with developed countries, the adoption of advanced automation technologies in Africa is very low. While there is a wealth of information available on many different aspects of the automation revolution for developing countries, particularly Sub-Saharan Africa, a framework for evaluating industrial innovation and technological adaptation specific to automation technology has yet to be developed systematically [41]. Meanwhile, the growing use of industrial automation, advanced robotics, smart factories, the internet of things, and 3D printing is changing manufacturing processes. “Whether or not emerging economies use innovative technologies to produce traditional manufactured goods, the use of new technologies will be disruptive”[42]. When compared to the number of companies that use automation and modern technologies, the adoption of flexible manufacturing systems in the African manufacturing sector is very limited. In 2014 Dewa et al.[43] conducted a study on Holonic Manufacturing Systems and their Applicability in an African Environment. The research discovered that 107 of the 158 respondents still use traditional machinery for production (Lathe, Milling, Drilling, etc.). Only 40 of the investigated sample's firms had flexible machinery such as CNC technology, with 11 firms having both.

Although the number of African manufacturing firms that use flexible manufacturing systems is small, many, if not all, want to improve their businesses by implementing advanced manufacturing concepts and technologies. In order to implement these advanced manufacturing concepts, certain challenges must be overcome. Initial implementation costs, the availability of skilled personnel to operate these new technologies, as well as maintaining and sustaining them, are some of the major challenges that manufacturing firms face hence we will try to investigate these challenges.

### *2.3 Challenges in advanced manufacturing and FMS in Africa*

In general, there are a lot of challenges faced by manufacturing companies. In order to improve quality, flexibility, productivity, and performance efficiency in today's manufacturing environment, industries must address issues such as the manufacturing skills gap, supply chain, and inventory management, robotics and automation integration, and the use of the industrial internet of things (IIOT). Fortunately, these issues can also be leveraged to strengthen the manufacturing industry's capabilities. A company that fails to meet technological challenges faces the additional challenges of introducing new products/services, innovation, and business models [44]. Flexible manufacturing systems are very expensive to implement, and access to finance is one of the most significant challenges that African manufacturing firms face. Lack of access to affordable finance is consistently cited as the most significant barrier to implementing projects on the ground by private-sector investors in the Grow Africa network[45]. Another major challenge in today's advanced manufacturing sector is a skills gap, with Africa bearing the lion's share of the burden. Because university curricula are outdated and faculty competencies have not been upgraded to cope with growth, most engineers who graduate from African universities lack the necessary skills and competencies for the modern manufacturing sector. There is a need to (re-)train the existing workforce for them to understand and use new and modern technologies. One of the primary causes of the global skills shortage is a misalignment between what schools teach and what employers require. STEM education continues to have many flaws. The “one-size-fits-all” approach that is frequently used promotes standardization while subverting innovative STEM approaches [46]. The current skill shortage is having real-world consequences. Of the CEOs who were extremely concerned about the availability of key skills, 65 percent of African CEOs (global: 55 percent) stated that the skills shortage was preventing them from effectively innovating, while 59 percent (global:47 percent) admitted that their quality standards and customer experience were being negatively impacted [47].

From research [48] data, sub-Saharan African workers have lower levels of digital skills than workers in other regions, even among the small portion of the labor force that uses LinkedIn, which accounts for an average of 4% of the labor force in the 27 Sub-Saharan African countries for which LinkedIn data is available.

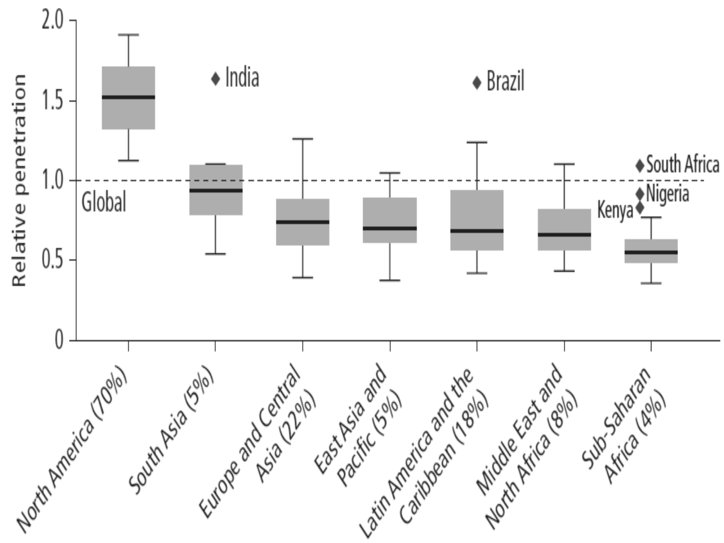



**Figure 4:** Digital Skills in Sub-Saharan Africa Relative to Other Regions
Source: World Bank calculations using LinkedIn data (share of total regional working-age population).

Another major challenge confronting the sector is poor and deteriorating industrial infrastructural services. Most African manufacturing industries have the subpar infrastructure, which leads to low productivity and a loss of confidence in the sector. The investor wishes to invest in the manufacturing industry, but the risk involved is too great due to the poor and insufficient industrial infrastructure. Africa has been classified as a high-risk investment destination. But do the challenges outweigh the opportunities that the region can provide to investors from across the continent? It's possible that many of the conditions investors seek aren't always found in the same place. Uncertain economic and political backdrops, as well as major challenges such as administrative hurdles and infrastructure gaps, can stymie investment.[49]

The reliable supply of electricity is a critical component of industrial infrastructure. Most of the machinery in the manufacturing sector are powered by electricity. Unfortunately, ensuring a consistent and adequate supply of electricity is a major challenge in Africa. Given income levels and the electric grid footprint, sub-Saharan Africa's rate of access to electricity is significantly lower than it could be[50].

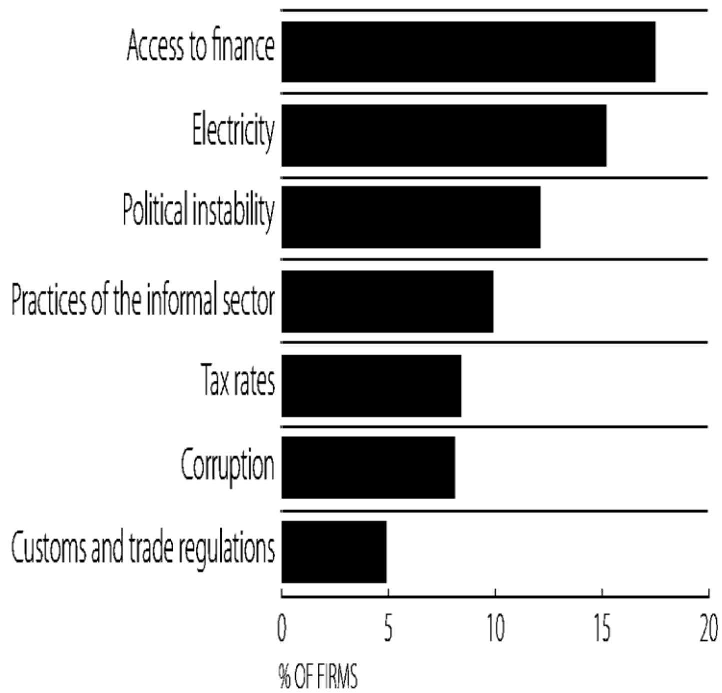



**Figure 5:** African firms' most common operating constraints (2015 or most recent year)
*Source: African Economic Outlook 2017 (OECD, AfDB, UNDP)*

Ateba et al. [51] conducted a study on the importance of electricity supply sustainability to industrial growth, and it was discovered that unsustainable electricity supply for the industrial sector, as well as poor sustainability, has a negative impact on South Africa's industrial growth [48]. Another major challenge in the African manufacturing industry is access to the internet. In the industrial internet of things, connectivity is critical. The smart manufacturing sector promises access to real-time manufacturing data, control of production flow, access to supply chain data, real-time access to inventory records, and other benefits. The internet can be used to access all of these processes.

According to the International Telecommunications Union (ITU), which monitors internet usage globally and by country, only one in every five people in sub-Saharan Africa used the internet in 2017[52]. Africa continues to lag behind both developed and developing nations in several key indicators for the 4th Industrial Revolution(4IR), particularly infrastructure, technology access, and skills training[53].

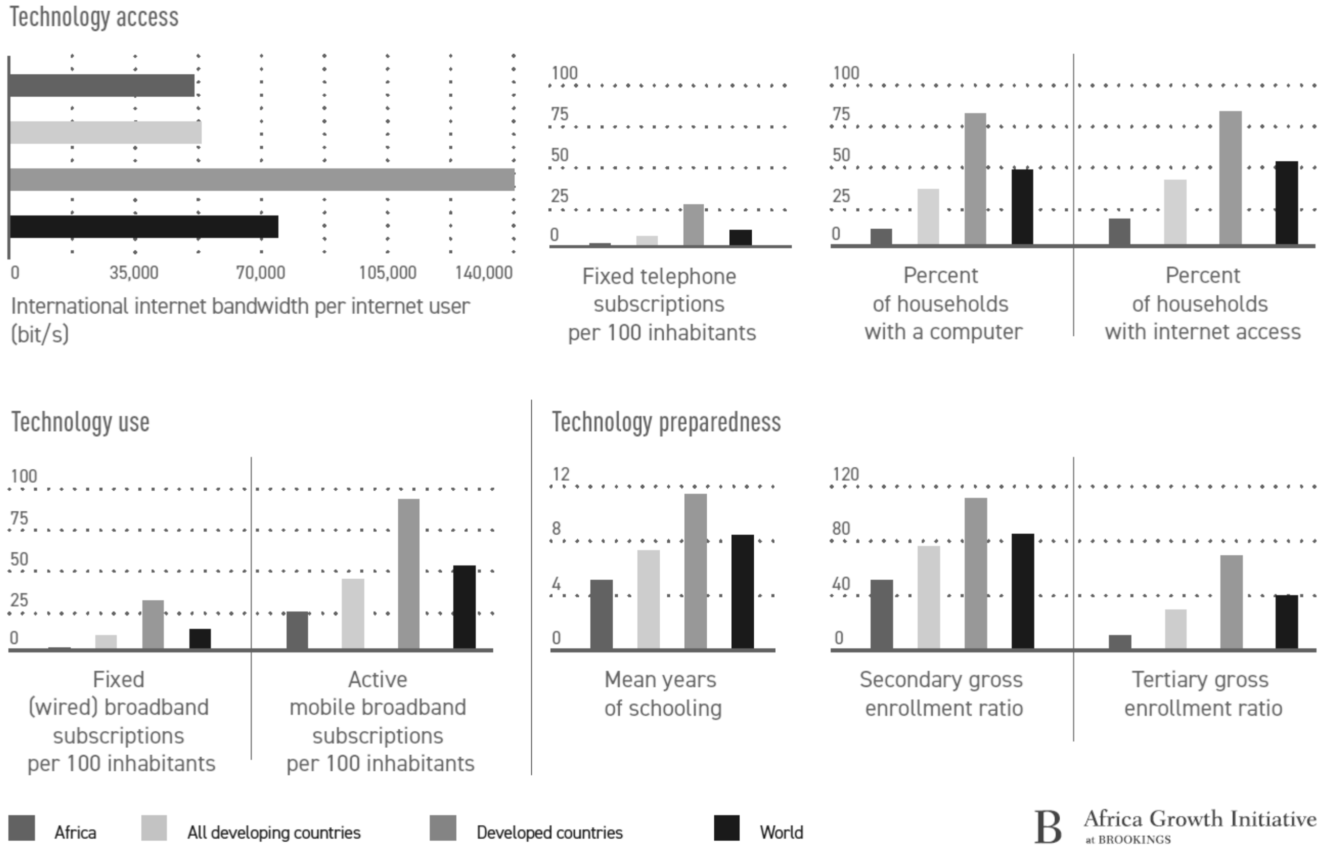



**Figure 6:** The Digital Revolution in Africa compared to developing countries and the world
Sources: Hebatallah Adam, "The Digital Revolution in Africa: Opportunities and Hurdles,"[54]

These challenges must be overcome in order to implement or adapt these advanced manufacturing technologies. The use of technology, the availability of skilled personnel, access to adequate industrial infrastructure services, the use of information technology, and the implementation of feasible and sustainable industrial policies are all important components of the modern manufacturing sector.

## 3.0 RESEARCH OPPORTUNITIES AND KNOWLEDGE GAP IN THE FLEXIBLE MANUFACTURING SYSTEM.

Although a flexible manufacturing system has been successful in terms of flexibility, improved product quality, increased return of investment, and overall manufacturing sector progression, the concept still has some limitations. The current flexible manufacturing system is not adaptable enough to respond to customer requests in real-time. Due to shortened product life cycles, market liberalization, intense competitive pressures, and constantly changing customer requirements, enterprises are being compelled to gradually rebuild the nature of their production to large-scale production and small series with a diverse range of products[55]. There is still a long way to go before manufacturing can be improved to the level required to match all principles with all aspects [56]. A significant proportion of cutting-edge manufacturing technologies are still in their early stages, and several obstacles and gaps must be overcome before they can become a reality.

The following areas remain as research opportunities in flexible manufacturing:

1. customization
2. real-time response
3. autonomous monitoring
4. predictive maintenance
5. decision making
6. self-optimization
7. self-configuration

Furthermore, effective control and flexibility of FMS can be achieved with the help of artificial intelligence (AI) and machine learning, additive manufacturing, generative design, and the industrial internet of things (IIOT). These advanced manufacturing features are relatively new and will necessarily require extensive research to fully understand their implications. In the context of Africa, there is a significant knowledge gap. Because the sector's adoption of these advanced manufacturing concepts is so limited, determining the impact and gaps of FMS on the continent is difficult. There are only a few African universities dedicated to teaching and learning about flexible manufacturing systems. Designing an intelligent, more flexible manufacturing module that can accommodate cutting-edge manufacturing features will not only boost the system's knowledge profile but will also elevate it to a much higher level of dimension and intelligence.

### *3.1 The adoption of FMS to improve manufacturing processes in Africa*

The implementation of advanced technologies in manufacturing processes aims to improve the overall production process. The manufacturing sector is constantly evolving, necessitating the use of advanced and smart technologies to keep up with the growth of change. Advanced Manufacturing Technologies are defined as a set of computer-based technologies which include: computer-assisted design, robotics, technology groups, flexible manufacturing systems, automated material handling systems, storage and retrieval systems, numerically controlled computer machine tools, bar codes or other automated identification techniques, and computer-integrated manufacturing [57]. To be competitive and efficient in the global market in terms of quality, flexibility, low operational costs, production time efficiency, and overall optimized performance of a manufacturing plant, African manufacturing firms must employ these advanced technologies. The adoption of these advanced concepts in the African manufacturing industry will not only increase manufacturing added value to GDP but will also transform the entire continent, resulting in economic growth and development.

#### *3.1.1 Flexible manufacturing systems*

To compete, the African manufacturing plant will need to be able to respond quickly to changes in conditions, customer preferences, innovation, and social requirements. FMS concepts provide benefits such as flexibility, agility, adaptiveness, responsiveness, rapid product realization, and robust manufacturing. Manufacturers will need to respond quickly to a much broader range of product specifications in terms of design and production [58]. Because most African manufacturing plants have low and static productivity, implementing these modern concepts will improve and accelerate the sector's growth.

#### *3.1.2 Benefits of adapting FMS*

The flexible manufacturing system is an advanced manufacturing concept that promises a lot of benefits in the manufacturing industry. Reduced manufacturing costs, increased labor productivity, increased machine efficiency, improved quality, increased reliability, reduced parts inventory, shorter lead times, and enhanced production rate are some of the advantages and benefits of FMS[59]. These are qualities that the growing African manufacturing industry need in other to win the minds and heart of the consumers. Since the market size of Africa is big, flexibility is a key element in terms of satisfying customer needs.

#### *3.1.3 Integrating new advanced manufacturing technologies into the FMS concept*

Although there are numerous advantages to a flexible manufacturing system, there are a few possible downsides that should be considered. Constraints may also hinder FMS's efforts to become more adaptable, requiring more planning to overcome those obstacles. Integrating new manufacturing technologies (such as AI, smart sensing capabilities, 3D printing, generative design, IIOT, and 5G connectivity) in FMS will significantly improve the concept to a much higher degree. Although these technologies are new and expensive to implement in the FMS environment but are also an opportunity that can lead to a much better version of the manufacturing concept.

#### *3.1.4 Artificial intelligence (AI)*

Artificial intelligence is a branch of computer science. It is concerned with methods and technologies that enable a computer to perform tasks that would require intelligence if performed by humans [60]. Deep learning and advanced cognitive computing methods have begun to find use in manufacturing systems for automated visual inspections, fault detection, and maintenance.

Reinforcement learning methods are being actively applied to material handling systems and production scheduling[61]. From 2019 to 2027, the AI share of the manufacturing market is expected to grow at a compound annual growth rate of 39.7 percent, reaching $27 billion by 2027[62]. The benefits of artificial intelligence in manufacturing are enormous; implementing it would not only improve but also transform the entire production system.

#### *3.1.5 Smart sensing capabilities*

Smart sensors, which gather and control data in real-time, are one of the most important technologies used in advanced manufacturing. The data sent by this sensor was used by systems in the manufacturing plant to perform certain actuations. The more intelligent a sensor becomes, the more accurate and timely the data it can send. In general, these smart sensing capabilities are a massive advantage for these data-driven manufacturing firms.

### *3.1.6 3D printing*

In contrast to subtractive manufacturing methodologies, 3D printing, also known as additive manufacturing or rapid prototyping, is the process of joining materials to make objects from 3D model data, usually layer upon layer[63]. South Africa is one of the African continent's most active countries in promoting additive manufacturing research, both in academia and industry, through various support programs. For example, the South African Department of Science and Technology (DST) has invested significantly in AM research over the years[64]. It is very difficult to produce certain complex parts using traditional machining techniques, but with the use of additive manufacturing, complex parts can be produced more easily and quickly.

### *3.1.7 Generative design*

A generative design tool employs a computer and an algorithm to synthesize geometry to generate a new design entirely on its own. With the assistance of artificial intelligence, the computer can generate a plethora of design options based on the parameters provided. Because of the significant increase in computing power available, these tools have recently gained popularity in the design community[65]. These concepts can optimize the use of materials in manufacturing, lowering costs. This concept is gaining traction globally, and if the African manufacturing industry wants to keep up, adopting it will be one of their best chances to compete.

### *3.1.8 Industrial internet of things*

The Internet of Things (IoT) is made up of "Things" (or IoT devices) with remote sensing and/or actuating capabilities that can exchange data with other connected devices and applications (directly or indirectly)[66]. The Industrial Internet of Things (Industrial IoT) is made up of a multitude of devices that are linked together by information and communication software. The resulting systems, and even the individual devices that constitute them, can monitor, collect, exchange, analyze, and act on information in real-time to intelligently change their behavior or their environment – all without the need for human intervention[67]. This concept enables real-time remote access and control of manufacturing components and data. It also provides customers with access to supply chain and logistic data services.

### *3.1.9 5G Network connectivity*

The introduction of the internet of things accelerates the growth of connectivity. As more devices connect to the internet continuously, the current 3G and 4G internet connections become overburdened, necessitating the development of 5G networks. 5G internet provides significant additional capacity to provide high-speed services and connect large numbers of devices, but lower latency is a key differentiator that distinguishes 5G from existing wireless connectivity solutions and opens the way for manufacturers to achieve truly deterministic levels of control[68]. 5G connectivity's wireless flexibility and low-latency performance make it an ideal choice for advanced manufacturing systems.

[69] Some people believe that the use of advanced manufacturing technologies leads to higher productivity and lower employment; however, this is not always the case. Using these new technologies also generates new job opportunities, even if it necessitates retraining and upskilling the workforce[70]. These advanced technologies have created jobs such as data science, programming, cryptography, and so on. Adopting and implementing these advanced manufacturing concepts will necessitate the training of many skilled workers in African manufacturing industries. As a result, the continent's knowledge base will grow, the continent's industrial expert profile will improve, and there will be more room for research and development in the sector.

## 4.0 CONCLUSIONS

This study review manufacturing and its impact, as well as the state-of-the-art of FMS and its adoption in Africa. Furthermore, the study discusses manufacturing challenges and research opportunities in the sector. Based on a review of the literature, the contribution of manufacturing to GDP in Africa is quite low in comparison to the rest of the world. Findings from the study reveal that the use of innovative manufacturing technologies and ideas such as FMS is limited. The study also shows that companies that implement FMS concepts in their manufacturing process register some significant improvement in their plant's performance. Additionally, the majority of African countries seek to enhance their manufacturing sectors by creating attractive industrial policies however, it has not translated to the implementation of adequate advanced technologies in the manufacturing sector.

The assessment of the level of adoption and implementation of FMS in the African manufacturing sector is a critical step. The findings of this study back up the hypothesis that Africa's manufacturing industry is underdeveloped, with little adoption of innovative manufacturing technology and concepts.

Based on this study, African manufacturing companies should consider implementing the FMS concept in other to be competitive. Furthermore, Policy makers in the industrial sector should reassess their policies and come up with attractive incentives to promote the implementation of FMS. Subsequently, the introduction of artificial intelligence (AI), 3D printing, generative design, industrial internet of things, and big data into flexible manufacturing opens up huge research potential to be explored in Africa.

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