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(RESEARCH ARTICLE)

An Assessment of the Implementation of Industry 4.0 in Zimbabwean Manufacturing Industries

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Abstract

The advent of technological development and integration of many fields including digital, physical and biological systems are key to the success of the Fourth Industrial Revolution, (FIR). Embracing of industry 4.0 by organizations is the key to global competitiveness and on the contrary, failure to adopt FIR may cause countries to lag behind in terms of economic development. The current studies have not fully covered on the use as well as levels of industry 4.0 implementation within developing countries. Most developed countries have put in place public policies that focus on implementing industry 4.0 in their respective countries. This means that it becomes critical, if not imperative, that developing countries like Zimbabwe also take steps to adapt industry 4.0 so as to remain relevant and competitive in the global economy as well as not be adversely affected by these technologies if not adopted. Zimbabwe, like most developing countries encounters a lot of problems in its endeavor to fully implement FIR technologies such as lack of commitment, infrastructure and lack of skilled workers. The objective of this study is to assess the implementation levels of industry 4.0 in Zimbabwean Manufacturing Industries, identify and discuss the challenges as well as issues faced by the organizations as well as coming up with recommendations in the implementation of industry 4.0 framework.

Keywords: Industrial Revolution; Industry 4.0; Manufacturing Industry; Developing Countries; Technology

1. Introduction

The world over, manufacturing industries are undergoing significant transformations and moving towards an age of digitalization in a bid to ensure that they reach a high level of efficiency. Therefore, the efficiency levels in an organization can be improved, through introduction as well as implementation of new technologies which move with the changing times and this encompasses the automation of the various industrial processes. The various concepts are such as big data, machine learning, robotics, internet of things (IoT) are the backbone of the 4th industrial revolution or industry 4.0.

The world is currently existing in a rapidly changing and developing environment within which disruptive trends as well as technologies such as Robotics, the Internet of Things (IoT), Artificial Intelligence (AI) as well as Virtual Reality (VR) are causing huge shifts in the way people work as well as live. The FIR in essentiality is the advent of "Cyber-Physical Systems" which encompass entirely new capabilities for machines as well as people [1]. While these capabilities are reliant on the technologies and infrastructure of the Third Industrial Revolution, the Fourth Industrial Revolution represents entirely new ways in which technology becomes embedded within societies and even our human bodies.

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The third industrial revolution, also referred to as the digital revolution, involved the development of computers and information technology (IT) since the middle of the 20th century. The fourth industrial revolution (FIR) emanated from the third but is considered a new era rather than a continuation because of the explosiveness of its development and the disruptiveness of its technologies.

According to Professor Klaus Schwab, Founder and Executive Chairman of the World Economic Forum and author of The Fourth Industrial Revolution, the new age is differentiated by the speed of technological breakthroughs, the pervasiveness of scope and the tremendous impact of new systems. One of the defining characteristics of this industrial revolution is that it is merging the physical, cyber and biological systems together [2]. This has the potential of boosting economies and drastically improving standards of living. This paper focuses on determining the implementation levels of industry 4.0 in Zimbabwean Manufacturing Industries, to identify and discuss the challenges as well as issues faced by the organizations as well as coming up with recommendations in the implementation of industry 4.0. Thus, in the time of globalization, the adoption of industry 4.0 is therefore, one of the key industry enablers to achieve the desired production levels at the same time minimizing the cost of production [3]. The research paper is organized as follows, section 2 outlines the research methodology, Section 3 gives literature review on Industry 4.0 and the implementation frameworks in manufacturing, Section 4 gives the survey results and the results analysis, Section 5 outlines the proposed framework implementation, and Section 6 gives the research conclusion.

2. Research Methodology

2.1. Objectives

The primary aim of the research was to assess the current implementation levels of Industry 4.0 technologies in Zimbabwean Manufacturing Industries as well as to come up with an effective way of implementing Industry 4.0 within these industries. In order to meet the aim, the following objectives were formulated:

- To establish the industry 4.0 techniques that are to be implemented in Zimbabwe.
- To assess the key drivers in implementing industry 4.0 technologies in Zimbabwe.
- To identify challenges faced by Zimbabwean industries in implementing industry 4.0.
- To develop a framework that helps Zimbabwe manufacturing industries to implement industry 4.0.

2.2. Research Questions

The guiding research questions were as follows:

- What is the industry 4.0 techniques being implemented in Zimbabwe at present?
- What are the key drivers in implementing industry 4.0?
- What challenges are being faced by Zimbabwean industries in implementing industry 4.0?
- What steps can be put in place by Zimbabwean manufacturing industries so that they can successfully implement Industry 4.0?

2.3. Research Methods

In order to meet the research objectives, the methodologies outlined in Table 1 were implemented

Table 1 Research Methods

Objective	Methodology	Tools
To establish the industry 4.0 techniques that are to be implemented in Zimbabwe.	Quantitative (Survey)	Questionnaire
To assess the key drivers in implementing industry 4.0 technologies in Zimbabwe	Quantitative (Survey)	Questionnaire
To identify challenges faced by Zimbabwean industries in implementing industry 4.0.	Quantitative (Survey)	Questionnaire
To develop a framework that helps Zimbabwe manufacturing industries to implement industry 4.0.	Literature Review and analysis of results	Content analysis

A closed ended questionnaire was developed and sent out to 20 manufacturing companies. The questionnaire was designed in such a way that an organization would outline from the list, Industry 4.0 technologies which they are currently utilizing, the key factors behind their need to implement the technologies as well as the challenges they are facing in the implementation.

2.4. Scope of Study

The questionnaires were sent out to 20 Manufacturing Companies within Harare and the organizations' grouping in terms of their products are as illustrated in Fig 1 below.

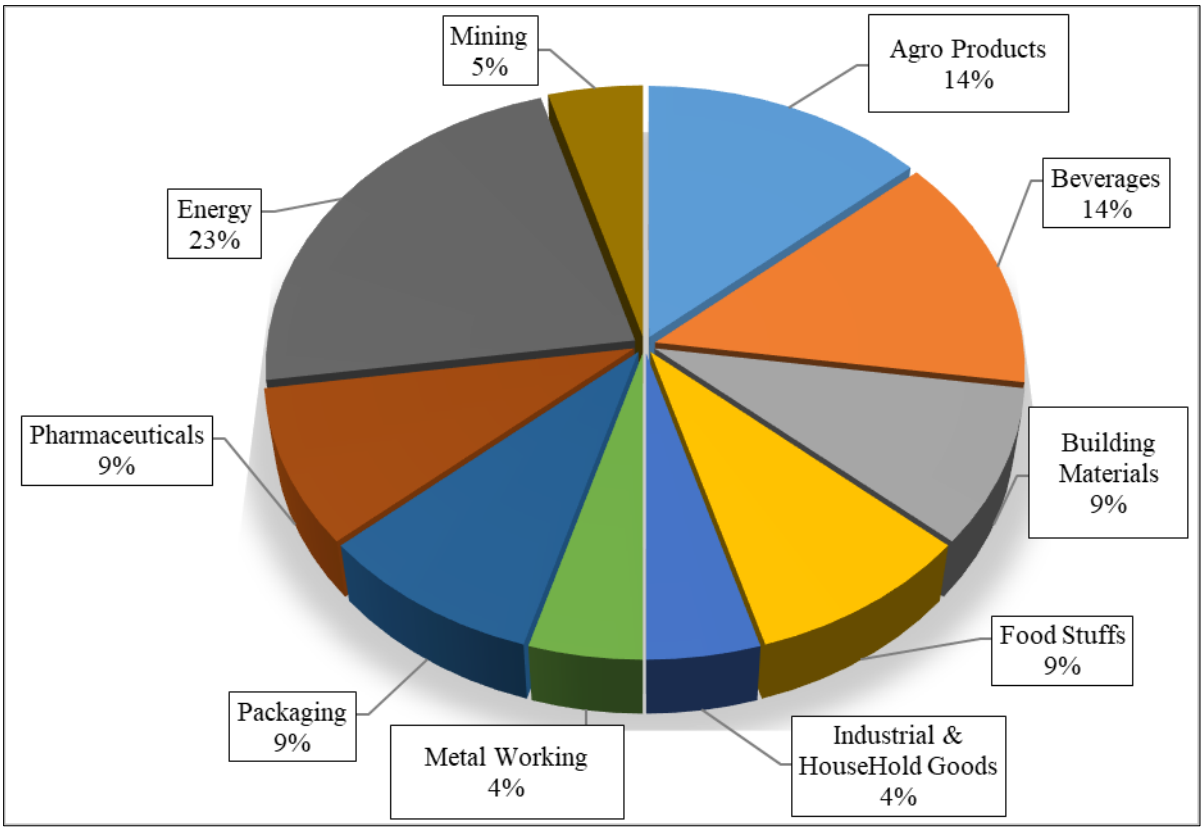

Figure 1 Company Grouping According to Sector

3. Literature Review

3.1. Industry 4.0

The desires of the consumers in terms of products and services are always changing and the rate at which they change will continue accelerating; in light of this, manufacturing organizations which do not place focus upon new technologies, run the risk of falling behind their fellow competitors and becoming obsolete [4].

The fourth industrial revolution, generally referred to using the term 'industry 4.0' aims to make use of artificial intelligence to come up with improved products or services which take into account the consumer behavior as well as varying preferences at a significantly reduced production cost by the automation of the production systems basing on the exchange as well as use of data in real time [5].

A revolution in essence is a major shift in terms of the way we think and the way we do things or a noticeable or drastic change in the process of performing given tasks [6]. The fourth industrial revolution is a reality currently being experienced globally and is essentially focused on bringing many things together, interconnecting them and having them work in perfect harmony [7].

Mankind is continuously in search for improvement in the modes of production, and this improvement will come in the form of a connection between man, the machines and the general process [8]. The amalgamation of related technologies

has seen the advent of the Fourth Industrial Revolution to revolutionize manufacturing and other industries. For example, the Framework of the Smart Factory of FIR [9] has seen the amalgamation of physical resources, industrial network, cloud and terminals for supervision and control.

Although there has been shrinking of space as well as operation in the manufacturing industry within Zimbabwe, the few existing ones have been challenged to follow global trends in industrial technology. The organizations have been perceived to have mechanized their operations in line with FIR and this has seen a boost in productivity and the economic survival at large.

The other components of the FIR comprising of robotics, Internet of Things (IoT), cyber security, big data, additive manufacturing and augmented reality, have also seen their way into the industry and factories in Zimbabwe.

In summary the FIR is the amalgamation of Cyber Physical Systems (CPS), cloud computing, Internet of Things, Big Data, Robotics, Augmented Reality, horizontal and vertical integration, additive manufacturing and Cyber Security [10].

3.2. Industry 4.0 Technologies

3.2.1. The Industrial Internet of Things

The Internet of things (IoT) refers to the interconnecting network of smart devices, networking systems, sensors and software which allows physical objects to exchange data as well as acquire information [6]. The Industrial Internet of things, decentralizes analytics as well as decision making in the sense that, field devices are now able to communicate with one another as well as with more centralized controllers, when necessary, hence enabling real-time responses [11].

3.2.2. Big Data

The element of big data in essence refers to large volumes of complex as well as diverse data sense that have a huge weight on the decision making of an organization regarding its strategy [12].

3.2.3. Autonomous Robots

Robots find use in manufacturing industries where they solve difficult tasks which cannot be executed by a human being with ease; the required information or commands being provided by the operator who maintains control of the system and provides instruction to the industrial robots [13].

3.2.4. Simulation

These tools serve a critical role in promoting sustainable manufacturing processes within production related activities [12]. The simulation tools make use of data acquired in real time to create real time optimization on production operations [14].

3.2.5. The Cloud

The main idea of FIR is based on intelligent manufacturing, and to achieve this goal, there is a need for access to shared space for data storage, computation power, services and applications. Cloud computing is the solution for all the aforementioned needs [15].

In the case of Industry 4.0, an increased data sharing is needed across companies as well as sites so as to achieve faster reaction times [16]. The cloud enables several devices to share information with one another and this can entail various sets of machines on the factory floor or the entire plant and is termed Digital production [17]. Cloud computing is composed of various Information Technology devices and resources which offer processing as well as storage facilities in a virtual system as they serve multiple users [12].

Three models typically exist for Cloud Computing (CC); Infrastructure as a Service (IaaS), which offers the basic functionality such as data storage capabilities, Software as a Service (SaaS), in which the customer purchase is the factor on which access is dependent e.g. Enterprise Resource Planning (ERP), and Platform as a Service (PaaS), where on the cloud, customers are allowed access to their applications [12].

FIR also incorporates cloud computing as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., data networks, data servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [18].

Cloud computing, requires infrastructure i.e. the CPUs and storage well as service providers who lease or rent infrastructure and to the end users. In Zimbabwe, cloud computing has been made easy by the development of high-speed internet and cheaper resources e.g. through fibro links and WIFI by Liquid Telecoms and ZOL among others. It provides many advantages such as no initial investment for infrastructure, lower operational cost, scalability and no maintenance expenses [19]. Cloud computing is a lucrative option for businesses such as manufacturing, telecoms and others.

3.2.6. Additive Manufacturing

Also generally defined as 3D printing; it helps manufacturing organizations to significantly reduce their lead times, realize an increase in terms of mass customizations as well as incur a significant reduction in wastes [20].

In Additive Manufacturing, small lots of products can be produced using less raw materials as the process activities are produced by layer upon layer [12]. In contrast to mass produced goods, 3D printed products can easily be customized [21].

3.2.7. Cyber Security

In general, companies view solutions to be of high cost, but in essence, the total cost of implementing cyber security is not very high taking into account the potential negative effects that cyber-attacks would have on the organization [22]. As organizations open up the previously closed production shops, the cyber threats increase exponentially [23].

Most of the Zimbabwe industries have Cyber-physical systems (CPS), being at the core of the FIR, which are physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core" [24]. Cyber physical systems are complex systems that consist of sensors and other means to collect data; Big data (generated continuously); networks, through which the different components are connected to each other with the help of cloud; and an intelligent cyber core, that responds to the real time data to keep the factory working intelligently and autonomously [16] [25].

This technology has been in operation in Zimbabwe in bottling companies, food processing and mineral processing operations. CPS are what connects all the physical components, data and the cyber components connected to one another. CPS works by maintaining a cyber copy of the physical systems that helps in running the factories autonomously.

3.3. Industry 4.0 Implementation Frameworks

3.3.1. Technology Selection Framework

In the case of Industry 4.0, a framework for technology selection was developed by Hamzeh et al (2018). It aims to come up with a readily applicable, easy to use, simple and efficient framework for decision making use in Manufacturing Industries with regards to Industry 4.0 [26].

The framework aims to assist the organization in achieving its objectives by employing the use of combinations of manufacturing strategies as well as technologies. It consists of six systematically linked steps which are as illustrated in Figure 2 [26];

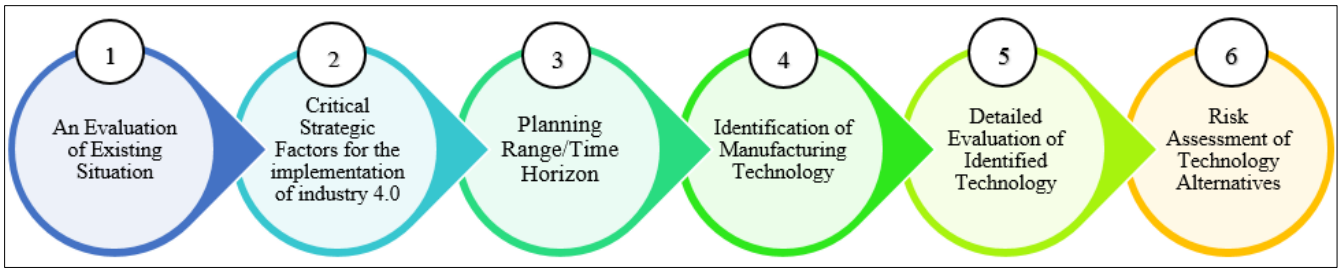

Figure 2 Technology Framework Selection Steps

3.3.2. Evaluation of Current Situation

The main driving factor behind industries employing Industry 4.0 techniques is the need to solve daily problems facing organizations as well as to improve the daily operations on the factory floor. In light of the fierce competition organizations face from their rivals, there is need for organizations to assess their performance indices in respect to market needs as well as demands in order to address their weak points so that they may be able to fight off the competition.

The organization has to benchmark its performance in relation to its competition in respect to a certain performance metric such as lead time, product or process quality, new product development and cost [27].

3.3.3. Critical Strategic Factors for Industry 4.0 Implementation

The next step involves identifying the various critical factors on which the organization plans to compete on with rivals. The organization has to redefine its business strategy in relation to the prevailing market conditions and the critical factors can enable the organization to achieve the redefinition taking into account the presently existing strengths and weaknesses of the manufacturing system.

3.3.4. Planning Range/Time Horizon

The third step is concerned with defining the planning range or time for the organization to compete on the critical factors defined in the previous step. A decision has to be made by the organization on whether the organization wants to compete on the factors on a long, short or medium term.

The output from this step would be a perfectly laid out strategy aimed at building a solid plan for the organization to move towards industry 4.0 and achieve its objectives.

3.3.5. Manufacturing Technology Identification

Since the organization has already outlined its critical objectives, need now exists to identify manufacturing technologies which fulfil these objectives. There is need to understand the technical conformance expected from the selected technologies and this step involves the input of a technology scanning process.

3.3.6. Detailed Evaluation of Identified Technology

This fifth step makes an effort to bridge the gap which exists between the business objectives of the organization and its manufacturing capabilities. The end goal of this step is to identify possible technologies that can be able to assist in the organization achieving its business and manufacturing goals. Each technology results in various opportunities as well as threats and these have to be determined.

3.4. Risk Assessment of Technology Alternatives

In order to improve the likelihood of success in regards to Industry 4.0, the risk factors associated with the implementation of each technology have to be identified. After a risk has been identified steps can be implemented to eliminate it or minimize its effects. A comprehensive risk assessment is therefore a crucial procedure in the framework. The most appropriate technologies are then selected.

3.4.1. Categorical Framework of Manufacturing for Industry 4.0 and beyond

The multi-layered implementation framework, assists individuals in understanding what it is that Industry 4.0 requires and how this requirement can be achieved [28]. The intelligence levels of Industry 4.0 enabling technologies is very much different, so they can be classified on different levels such as from low intelligence to high intelligence which in essence is: Control level, integration level and Intelligence level [29].

The production system, being the core section within any industry also enables a better understanding of the application of the technologies. Within the production system, the cost of production, yield as well as effectiveness of the technologies can accurately be measured [28]. In light of the different levels of automation as well as transparency, the production system can be divided into three levels of automation: Machine, production process and factory system [30].

By combining engineering as well as intelligence levels, a sequential framework is produced with nine intelligence applications; with three engineering level sections acting on the three intelligence levels as illustrated on Figure 3 [28].

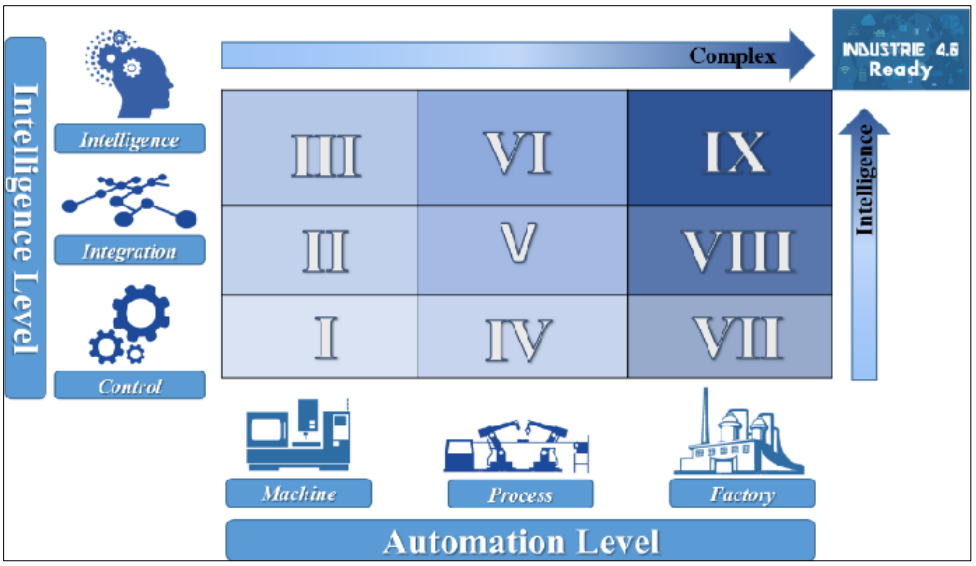

Figure 3 Industry 4.0 categorical framework of manufacturing [28]

The nine-intelligence applications progress from being of low intelligence and simple automation to a state of complex automation and high intelligence [28]. The framework is sequential in the sense that, the high-level intelligence applications are based on lower-level ones.

4. Survey Results and Analysis

The questionnaires for the survey were sent out to 14 organizations as illustrated in Figure 1 and of the 14 sent out, 9 were returned bringing about a 64% response rate from the selected pool of participants.

4.1. Organization Size

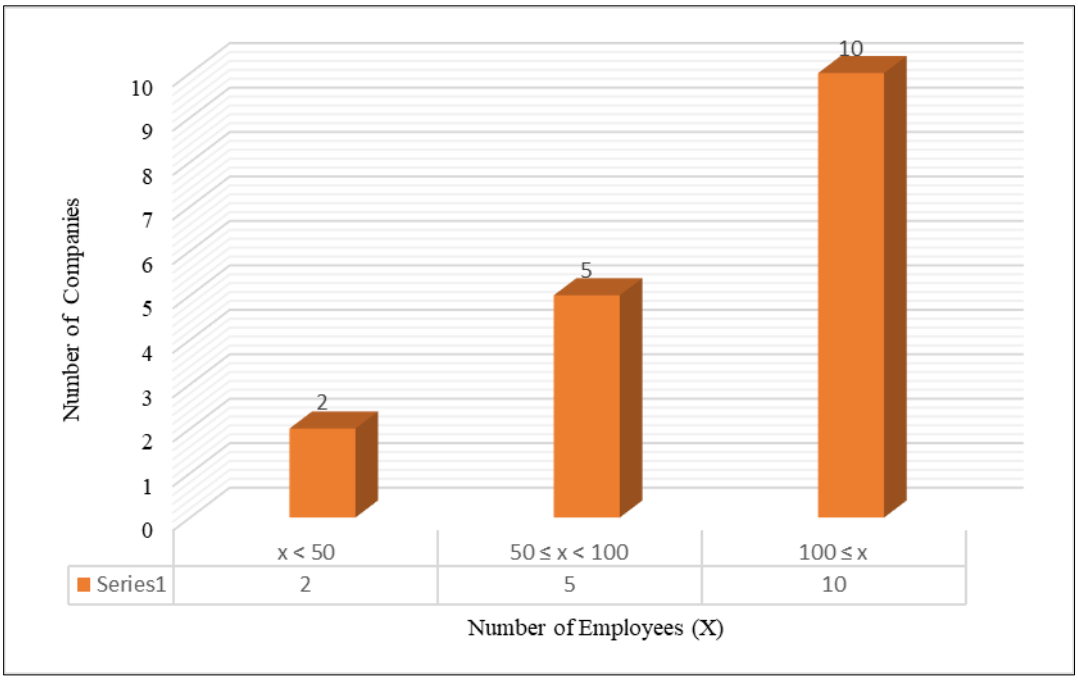

Figure 4 Company sizes in respect to employees

This section of the survey looked at the size of the organizations with respect to their employee base. The number of employees from the surveyed companies is represented on Figure 4. From the nine companies from which responses were obtained, only one company had an employee base of less than 50.

$$x < 1v$$

4.2. Industry 4.0 Technologies in use

The section looks at the industry 4.0 enabling technologies which are currently being used in the local Companies. Figure 5 gives the types of industry 4.0 technologies being implemented in the Zimbabwean manufacturing sector.

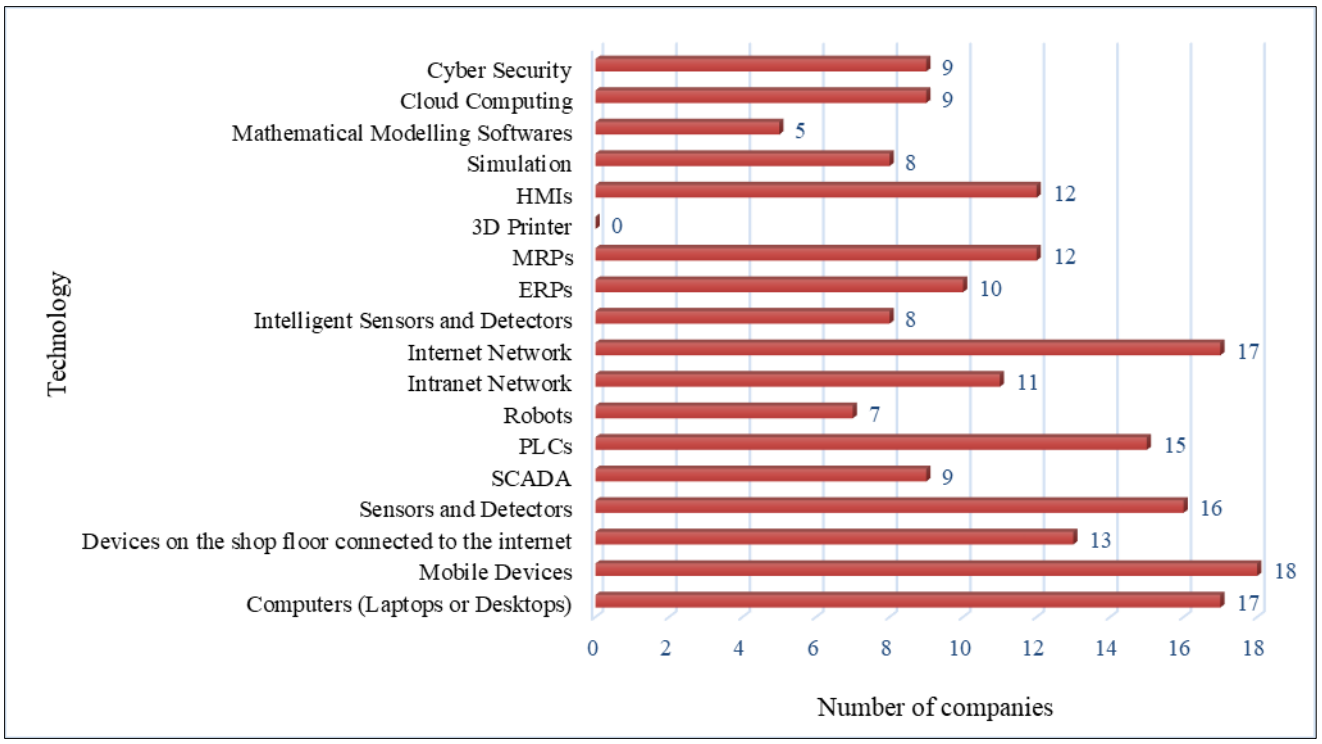

Figure 5 Companies employing Industry 4.0 Technologies

The most widely used enabling technologies are mobile devices, computers, sensors, PLCs and the internet. Additive Manufacturing (3D printing), Mathematical Modelling software as well as Simulation are rarely in use. 3D printing's unavailability in the sample population may be attributed to the nature of the products being produced by most of the companies in that set. Only a few of the companies would require additive manufacturing in their processes.

4.3. Implementation Drivers

This section looks at the various driving factors which are pushing organizations towards possibly implementing industry 4.0 within their daily operations. Outlined is the view of the Companies on the extent to which each factor is pushing them towards Industry 4.0.

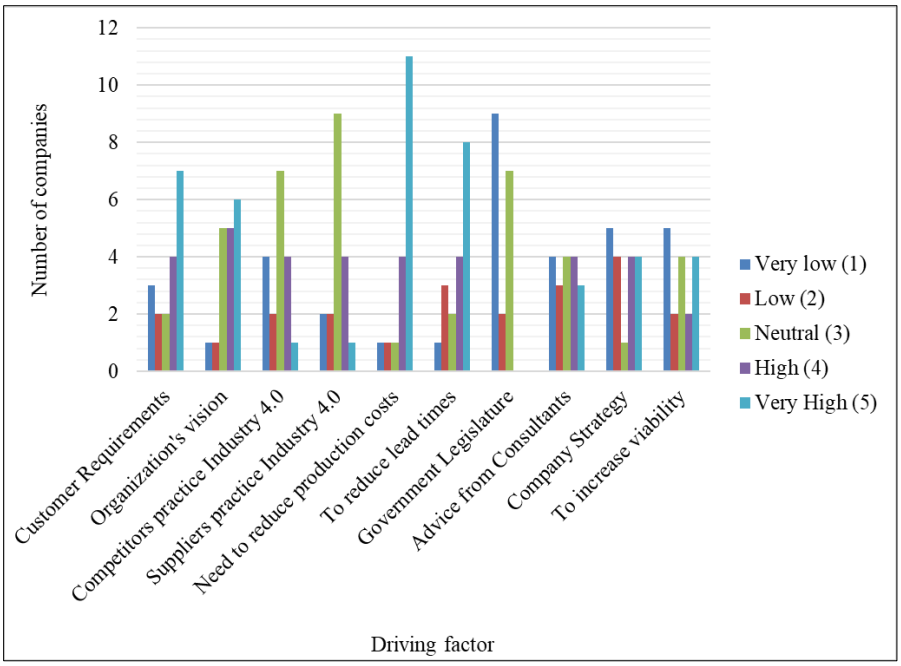

Figure 6 Factors Driving Companies towards Industry 4.0

There is a general need by most companies to reduce their overall production costs as well as lead times as shown in Figure 6. Consultants are doing very little in pushing their clients into incorporating Industry 4.0 into their daily operations. Government as well is also relatively silent when it comes to Industry 4.0 as noticeably shown by the lack of legislature pushing local manufacturing companies towards Industry 4.0.

4.4. Challenges in Implementation

The section looks at the various challenges in implementing Industry 4.0 within local manufacturing companies and the extent to which the factors are affecting the companies.

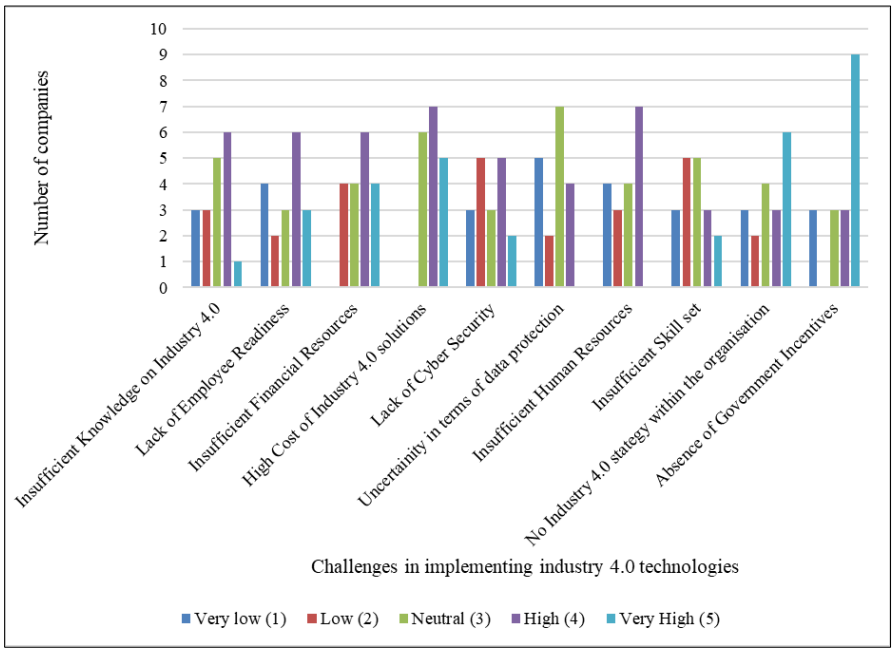

Figure 7 Challenges Being Faced in Implementing Industry 4.0

Figure 7 illustrates that, most companies in the sample population don't have an industry 4.0 strategy in place and hence that is their main challenge in implementing Industry 4.0 within their daily operations. With the high cost of Industry 4.0 solutions being outlined as well as lack of Government support in form of incentives, companies are struggling when it comes to implementing industry 4.0. A fear of cyber-attacks is also outlined and hence serious cyber security measures have to be crafted and implemented.

5. Framework Implementation

The Authors came up with an implementation framework for Industry 4.0 within the Zimbabwe Manufacturing Industries. The key to the implementation of Industry 4.0 is a step-by-step procedure which is outlined below.

5.1. Identification of Improvement Area

The first step is to identify areas within the organization which are in need of improvement and for which Industry 4.0 technologies may be able to offer a solution.

5.1.1. Root-Cause Analysis

There may be many possible reasons why the identified target area is not performing up to standard or why the identified problem is occurring, and these have to be identified at the initial stage so as to ensure that they are properly taken care of. A comprehensive root cause analysis is undertaken prior and the potential root causes are listed as outlined in Table 2.

Table 2 Output from Root-Cause Analysis

Identified Problem / Improvement Area	**Root Cause**
A detailed description of the identified area which requires improvement within the organization or a frequently occurring problem requiring an urgent solution for which Industry 4.0 may be a possible solution.	Root Cause RC_1
	Root Cause RC_2
	Root Cause RC_3.
	Root Cause RC_4.
	Root Cause RC_n

In order for the root causes with the highest probability of resulting in the problem being addressed first, the identified root causes are color coded on the table using the key outlined in Figure 8 below.

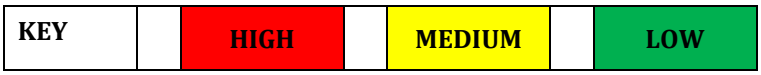

Figure 8 Colour coding for root-cause probability

The root causes which are red color coded are given first priority.

5.2. Project Prioritization

After improvement areas or problems have been identified, there is need to ascertain the order in which the issues will be tackled. It is not always the case that problems can all be tackled at once due to scarcity of resources hence the Pareto principle can be employed to schedule the tasks.

There are areas which are generally viewed to be giving headaches to the organization as well as areas which when improved will yield high returns for the company, it is these which should be given the highest priority.

5.2.1. Assessment of Current System

Perform an in-depth study of the current system being utilized by the organization to eradicate or curb the problem. The underlying questions are:

- How is the problem being handled at present?

- To what extent are the current methods succeeding?
- In what ways are they falling short?

Table 3 outlines the output of this stage in the implementation.

Table 3 Assessment Approach of Current System

Current System Being Employed	**Positives of Current System**		**Shortcomings of Current System**
A detailed description of the system currently being utilized in the area requiring improvement	Positive X_1		Drawback D_1
	Positive X_2		Drawback D_2
	Positive X_3		Drawback D_3
	Positive X_4		Drawback D_4.
	Positive X_n		Drawback D_n

5.3. Identification of Required Technologies

In order to solve the problem at hand, need now exists to identify possible Industry 4.0 technologies that can be employed. An in-depth study has to be carried out on the capabilities of each technology, its requirements to fully function as well as its cost to the organization.

Table 4 Technologies Required to Implement Proposed Plan

Proposed Plan	**Required Technologies**
A detailed outline of how the area is to be improved.	Industry 4.0 Technology T_1
	Industry 4.0 Technology T_2
	Industry 4.0 Technology T_n

The key outlined in Figure 9 is used to indicate the technologies which are already available within the organization and those which need to be sourced.

Figure 9 Colour Coding Key for Technology Availability

5.3.1. Risk-Assessment of Proposed Technologies

A comprehensive risk assessment is critical in the implementation of new technologies within the organization as it improves the chances of the innovation succeeding. Each new technology comes with risks which have to be identified and mitigated. After a risk relating to a technology has been identified, steps to eliminate or minimize the effects of the risks have to be outlined and their feasibility verified. Table 5 illustrates the approach to carry out the risk assessment for the proposed technologies

Table 5 Proposed Technologies Risk Assessment

Proposed Technology	Risk Associated with Technology	Measures to mitigate risk
Industry 4.0 Technology 1	Risk R_1	Methods to avert risk M_1
	Risk R_2.	Methods to avert risk M_2
	Risk R_n	Methods to avert risk M_n
Industry 4.0 Technology T_n	Risk R_1	Methods to avert risk M_1
	Risk R_2.	Methods to avert risk M_2.
	Risk R_n	Methods to avert risk M_n

The risks are color-coded with the aid of Figure 10 in order to indicate their anticipated severity. The risk mitigation measures' overall effectiveness is also color coded based on the color codes shown in Figure 10.

Figure 10 Colour Coding Key for Risk Assessment

The improvement team should only be content with their risk mitigation techniques if they all fall in the High effectiveness zone.

5.3.2. Assessment of Target Workforce

The target workforce are the organization's employees directly in charge of the area you intend to improve. Workforce assessment is achieved by implementation of the method given in Figure 11.

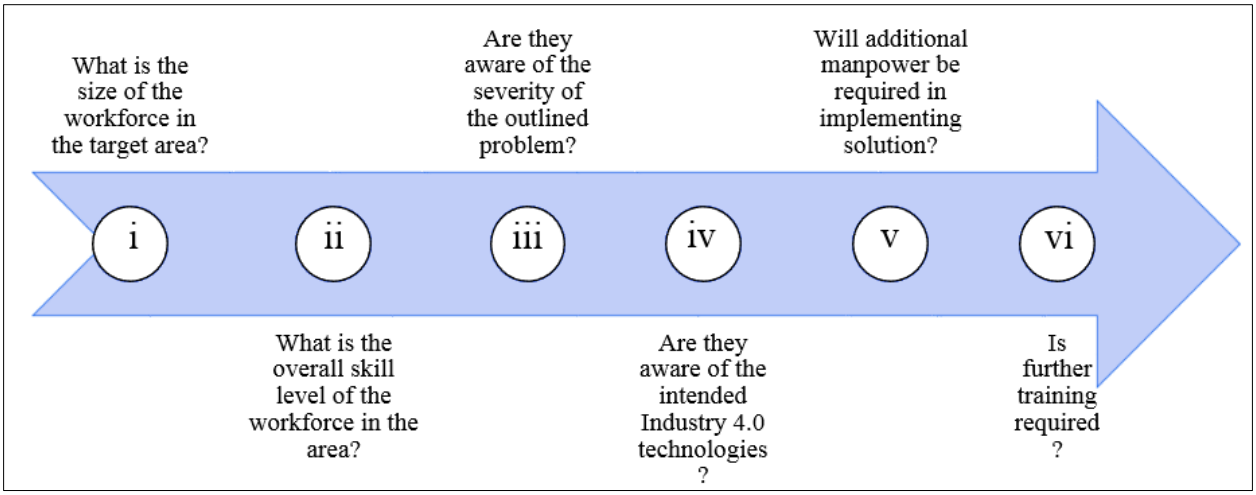

Figure 11 Work Force Assessment Approach

5.3.3. Map out a Clear Industry 4.0 Strategy

A clear and well laid out strategy is key in the achievement of any feat and Industry 4.0 is no exception. Produce a well laid out implementation strategy for your proposed solution, taking into consideration the above-mentioned steps.

Factoring in the financial obligations in terms of sourcing equipment, mitigating risks as well as training, an estimated time frame for project completion has to be produced. The targets as well as expected level of improvement have to be clearly outlined.

5.3.4. Align the Industry 4.0 strategy to overall Business Strategy

The aim of the improvement is to aid the organization to meet its business objectives and not to derail it from its course, hence the proposed Industry 4.0 strategy should be in sync with the overall Business Strategy.

5.3.5. Bring management on Board.

The Management is key in the failure or success of the implementation of a new technology or innovation within the organization as they usually have the final decision on whether or not to meet the financial obligations required.

- Is Management aware of the severity of the outlined problem?
- Is Management aware of Industry 4.0 technologies and the possible benefits it can yield to the organization in the highlighted problem area?
- If not, bring them up to speed.

5.3.6. Run Pilot Projects

Before embarking on full scale implementation of the proposed strategy, conduct small scale experiments to see how the proposed system performs. During this stage, the target workforce is trained, the risk mitigation methods are tested and the effectiveness of the solution is also ascertained.

5.3.7. If Pilot projects are successful, bring it up to full scale.

Full scale implementation has a huge financial burden to the Organization and hence should only be implemented when the factors necessary for success have been brought into play and this is mainly achieved through the prior stage of conducting pilot projects.

6. Conclusion

The Authors in this article, focused on the determination of the current state of implementation of Industry 4.0 within the Zimbabwe Manufacturing Industries as well as the Factors driving the Industries towards Industry 4.0 and the challenges they are facing in this endeavor. The Authors only managed to obtain responses from 18 companies and hence the results cannot easily be generalized but they give the view that the local organizations still have a mountain to climb in terms of reaching Industry 4.0 maturity.

Some of the technologies required for Industry 4.0 are already in existence in the Organizations, what is lacking though is their interconnectivity as well as optimization so that they may be utilized at their full potential. There is also a lack of Government support in the industry 4.0 initiative within Zimbabwe, highlighted by the absence of Government policies as well as initiatives in light of Industry 4.0. With the local Manufacturing Industries citing the high cost of Industry 4.0 solutions as a major drawback in their implementation efforts, Government incentives if available would smoothen the transition.

A more extensive survey on more Manufacturing Industries in other parts of the country may give a clearer picture on the state of Industry 4.0 implementation within the country and may also help to ascertain other challenges hindering the initiative. Future work may also be carried out on the Implementation framework to narrow it down and make it Industrial Sector based to improve on its effectiveness.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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