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Review of Disruptive Technology in Automotive Manufactruring

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Abstract

A study has been carried out on one of the first generation automotive assembly plant in Nigeria on their current level of assembly operations, automation and how to migrate to the industry 4.0. In the process, a comprehensive review of disruptive technology in the automotive manufacturing sector was carried out to find out the level of disruptive technology in the global automotive manufacturing industries. It was discovered that the industry 4.0 technology is already fully operational in the key global automotive manufacturing and assembly plants. This has positively impacted the automotive manufacturing industries and it comes with many benefits like employability, technology advancement, increases in revenue to the industry, and decarburization of the environment. The research has shown that with the knowledge of maturity model for the adoption of industry 4.0 in the manufacturing process, the organization could determine their industry 4.0 level at every point in time and the adoption could begin from a section in the organization before expanding to other sections, units or department. There is a need for the Nigeria automotive industries to start to migrate to the industry 4.0 level from either the body welding operation or the paint shop.

Keywords

Industry 4.0, Disruptive Technology, Automotive Industry, Manufacturing Technology and Robotics

1. Introduction

All through history beginning with the invention of the wheel in 3500 B.C., humanity progressed after 3500 B.C. by devising methods to create human autonomy. Since the invention of the wheel, numerous other innovations have led to the beginning of industrialization, beginning with the coal-powered steam engine and continuing with the development of alternative energy sources. This eventually led to the beginning of the mechanization of labor-saving processes, or the industrial revolution. It began with the invention of the first mechanized loom (Industry 1.0 Mechanization, 1784 AD). This was designed by Edmund Cartwright and constructed in 1785, it revolutionized the textile industry through the industrialization of weaving and was the first factory (Nayyar & Kumar, 2020).

Then the Industry 2.0 Mass Production came up next, also referred to as the Technological Revolution, which started in 1870 AD when interchangeable components and automation were introduced to the machine tool industry in order to create assembly lines. In 1870, Henry Ford was credited with coming up with this technology at the Detroit Automobile Company's production line. The telegraph, telephone, and electricity were among the inventions that changed human history and rewrote geopolitical boundaries, causing the First and Second World Wars as well as globalization.

Next was Industry 3.0, often known as automation, debuted in 1969 it was centered on Dick Morley's creation of the Programmable Logic Controller (PLC). As a result, mass manufacturing started to shift away from assembly lines, which still required labor but towards autonomous and automated mechanical machinery. The PLC lead the path to fully automated systems, then to the development of robotics. In order to make computers and telecommunications available to the general public, which started with the advent of the internet and the "World Wide Web", early microprocessors were developed with automation and the development of robots. This was attributed to Tim Berners-Lee in 1989, and the German government established a working committee to investigate the next step toward the development of automated enterprises (Anthony, 2018).

The outcome was the emergence of Industry 4.0, which describes the transition to a "smart" industry. To accomplish this, the entire supply chain will be transparent and manageable online. This encompasses both interacting with the outside environment and reading sensor input from a particular machine. Everyone agrees on just one thing, which is the transition needs to be tailored to each plant and partner. But every shift to the factory of the future must include a few crucial elements (Bauernhansl et al., 2014).

Manufacturing in this new era of machine learning requires little human intervention, transitioning from an input and output approach to a smooth conversation between humans and robots, the fourth industrial revolution. Machines are now equipped to make decisions and provide technical assistance, which has led to more transparent communication.

Disruptive Technology in Manufacturing

The Industrial Internet of Things (IIoT), industrial 3D printing, the introduction of virtual reality to the factory floor from the gaming industry, the rapid increase in the number and capabilities of factory and office robots, and artificial intelligence at all levels are some of the disruptive manufacturing technologies of today (Lu, 2017). Disruptive technologies have revitalized manufacturing at other times in history, just as these current technologies are doing today. The globally adopted name for disruptive technology is the Industry 4.0, a term that was introduced at the Hannover Fair in 2012.

Interoperability, information availability, technological assistance from artificial intelligence and decentralization of decision-making are the four pillars on which Industry 4.0 is based (Hermann et al., 2016). For the Internet of Things (IoT) to connect and connect people, machines, sensors, and devices, interoperability is required. The production of virtual representations of the real world is made possible by the accessibility of information in digital systems. Technical support is the aid offered by digital technology to assist people in resolving issues and coming to more educated conclusions. Decentralized decision-making refers to the idea that systems can operate freely, make decisions, and carry out tasks without human supervision. These viewpoints are unquestionably damaging. The goal of Industry 4.0 and IoT is to connect factories with suppliers, warehouses, and distribution networks in order to reduce costs and boost output (Nayyar & Kumar, 2020).

Robotics: Robotics is one of the recent disruptive technologies that enabled the greatest potential for application in the automotive manufacturing industry. In early phase of robotics, the majority of robots were simple and single-purpose machines. But because artificial intelligence technology has advanced rapidly, robots have now reached the possible uses we can hardly imagine. Robots are gaining high level of intelligence so they can perform multiple and complex tasks compared to simple machines with a few axes of motion. Robots could do a wide range of new tasks if they were able to learn, develop, and think like humans. Robots will live in a new world if they can learn from one another and from themselves. The promise of robotics seems endless (Batth et al., 2016). They are employed for an increasing range of jobs well beyond the production line. They are being built to read emotions and talk, robots recently advanced a step closer to human status when in 2017 it was granted Saudi Arabian citizen. As part of this evolution, some robots are also taking on uncannily human-like appearances. Industry 4.0 and the technologies it represents may be disruptive, but the disruptions they bring will be constructive and positive gains to our national automotive manufacturing industries and their manufacturing systems and our lives.

2. Literature Review

2.1. The Automotive Industry

A nation automobile industry is a crucial sector and one of the key economic drivers in that country (Gottschalk & Kalmbach, 2007). It directly or indirectly impacts every aspect of industry covering almost all products of steel, rubber, plastics and electronics. It also creates direct and indirect job opportunities to the nations of the world. According to ACEA (The automobile industry pocket guide, 2022/2023) in Europe alone 2.6 million people are directly involved and 10.2 million people are indirectly employed, which is about 5 times higher than those directly employed. All developed countries' economic development is largely based on its core industries, and one of those key industries is the automobile sector. A typical automotive project will require direct and indirect human resources from a large number of functional organizations and infrastructures. These human resources can come in the form of employees, suppliers, consultants, and partners who are located in a variety of locations across the country and the globe.

Africa was considered to be the second fastest growing market for vehicle sales on the globe according to (David, 2015), as a result of increasing population, which has been predicted to grow to 1.25 billion by 2025 and to 2.4 billion in 2050. In addition, over the past decade, six out of the ten fastest growing countries were from Africa with GDP of 4.7% growth in the sub Sahara region as of 2013 according to (Auboin et al., 2014). In 2014, Africa imported four times more automotive products than it exports, with automotive imports worth over $48 billion and exports worth only $11 billion according to (Deloitte, 2016). The major sources of used vehicles in Africa are the United States (US), Europe and Japan.

2.2. The Impact of Industry 4.0 on Automotive Industries

Cyber-physical systems (CPSs), the Internet of Things (IoT), and cloud computing are going to be incorporated into intelligent factories as part of the long-term strategic plan referred to as Industry 4.0 that is being developed by the German government. This will make it easier to modernize and transform the manufacturing technologies that are currently in use. It is anticipated that the production process will be almost totally automated, with very little or no involvement from human workers at all level of production (Nayyar & Kumar, 2020; Lee et al., 2015). The manufacturing systems in the age of Industry 4.0 have the ability to monitor physical processes, create the "digital twin" (or "cyber twin") of the physical world, and also make smart, perfect decisions through real-time communication and collaboration with humans, machines, sensors, and other devices as the case may require. This capability was not available in previous eras (Wang et al., 2016a). Intelligent production processes and embedded production system technologies are incorporated into Industry 4.0 in order to make possible a new technological era that has radically re-imagined industry value networks, production value chains, and business models. This is the result of the widespread acceptance of the fourth industrial revolution, which has brought about this event. A higher level of intelligence has been achieved by production systems, according to the hypothesis that underpins Industry 4.0, often known as the Fourth Industrial Revolution according to (Wang et al., 2016b). It enables all physical processes and information flows to be made available whenever and wherever they are necessary across a holistic manufacturing supply chains, multiple industries, small and medium-sized enterprises (SMEs), and large companies. Furthermore, it enables these processes and flows to be made available across a broad range of companies, from SMEs to large corporations. In order to make it possible for devices or machines to adapt their behaviour in response to a variety of circumstances and requirements, certain underlying technology is required for intelligent manufacturing. This technology must make it possible for the devices or machines to learn from their past experiences and increase their capacity for learning (McFarlane, 2003). All the technologies involved enable direct communication with manufacturing systems, thereby allowing problems to be solved and adaptive decisions to be made in a timely fashion. Some technologies also have artificial intelligence (AI), which allows manufacturing systems to learn from experiences in order to ultimately realize a connected, intelligent, and ubiquitous industrial practice.

Intelligent manufacturing which is also called smart manufacturing is a broad concept of manufacturing with the purpose of augmenting production and product transactions by making full use of advanced information and manufacturing technologies as stated by (Kusiak, 1990). It is regarded as an innovative manufacturing model since it is based on advanced science and technology. As a result, it offers significant improvements to the design, production, management, and integration of a typical product over its entire life cycle. Because of this, it has attracted a lot of attention. Utilizing a wide array of intelligent sensors, adaptive decision-making models, sophisticated materials, intelligent devices, and data analytics can help streamline the entirety of the product life cycle. This can be accomplished by combining these technologies with other cutting-edge innovations. There will be improvements made to the production effectiveness, product quality, and service level in the near future (Davis et al., 2012). A manufacturing company's ability to deal with the volatility and changes of the global market can considerably increase the company's competitiveness in the marketplace. An Integrated Management System, more commonly referred to as an IMS, will make use of artificial intelligence in order to deliver common functions like learning, reasoning, and acting. It is feasible to automate the material inputs, manufacturing mix, and production processes by making use of technology that is driven by artificial intelligence (AI). The monitoring and control of industrial processes in real time is another potential application of this technology (Koren et al., 2017).

2.3. Empirical Review of the Development in the Automotive Sector

The automotive industry sector is continually improving as a result of the fierce competition that exists among the numerous brands in the field, which calls for the application of systematic methods according to (Costa et al., 2017a; Antoniolli et al., 2017). Elimination of waste, reduction in price and increase in quality, are the main target and expectation of these company (Costa et al., 2018). For the objective of achieving continuous improvement in this area, there are two main methodologies that may be used. These techniques depend on the quantity of capital that investors are prepared to commit as well as how willing they are to make adjustments. Some authors have discussed the shift from a manually operated system with high labour man-hour requirements to a fully automated system as a disruptive situation that is solely based on technological advancements. The fully automated system is capital intensive and requires higher investments, but it promotes a massive decrease in project completion time and significantly improves quality. The manual method was being phased out for a complete automated method during this transition, which is more expensive and capital intensive (Costa et al., 2017b; Moreira et al., 2017).

But despite the fact that the focal point is the technical, the effects are also noticeable in the management component of each production system (Magalhães, el al., 2019). But, there are approaches that do not require much technical improvement, and with little investments, and management tools related to lean manufacturing system will promote significant improvements in the process for waste elimination and improvement in the product quality (Rosa et al., 2018). However, Value Stream Mapping (VSM), Line Balancing, Standard Work, SMED, Visual Management, and 5Sigma enable outcomes to be obtained more quickly and with a smaller investment commitment. It is reasonable to note that all lean technologies are put to substantial use in the automotive sector (Stadnicka & Litwin, 2019). By starting with a semi-automated system and working the way up to a completely automated system (Araújo et al., 2017) developed a novel idea for manufacturing suspension mats for the automotive industry, enabling him to achieve productivity increase of up to 40%. The reduction of repetitions that were both required and feasible was done in response to the problems of low productivity. This significant gain in productivity was due to a restructuring of the layout of production equipment, which enabled the allocation of two employees to other more important tasks, eliminating the need for unnecessary in-between manipulations. There was also an improvement in the flexibility of the production equipment. A new idea of equipment setup for shafts assembly as developed by (Costa et al., 2017b) which is used in the process of operating a car windscreen. The repeated mistakes that are typically connected to the manual assembly of these components won't happen anymore, thanks to this creative concept for assembly. The fully-automatic machinery had a production rate that was 19% greater than the initial semi-automatic machinery, a noteworthy improvement in quality, and a comprehensive inspection of each and every component that was manufactured. In order to reduce cycle time and place more of an emphasis on the numerous assembly procedure that are carried out on various pieces of machinery.

A brand new concept of equipment setup for shafts assembly which is used in the operation of car windshields was developed by (Costa et al., 2018). This new concept of assembly permitted the elimination of the appearance of tenacious defects related to the manual assembly of these assemblies. In addition to the significant increase in quality and 100% inspection of the assemblies produced, there was an increase in the production rate compared to the initial semi-automatic equipment by 19%. In order to improve cycle time and concentrate on different assembly activities performed on different equipment and in single equipment, a new integrated assembly concept was also developed by (Moreira et al., 2017).

This developed concept and the associated piece of equipment essentially was targeted to eliminate different stages of production, as well as the resultant intermediate stocks. The equipment allows a continuous flow, minimizing the efforts of the internal logistics, supply chain. A piece of equipment capable of assembling a sets of parts in an exceptionally flexible way achieving a cycle time reduction of more than 35% was invented by (Nunes & Silva, 2013). The extremely fatigue manual assembly operations were removed, reducing the risk of occupational diseases such as tendonitis. The eradication of the problems of randomness caused by the operation of cutting wires used in car seats was carried out by (Magalhães et al., 2019) using an innovative system of separation and alignment provided with artificial vision. This facilitated the easy operation of passing these components for the next operation, plastic over injection.

For the improvement of the productive system in tire construction, (Santos et al., 2018) stimulated a technical upgrade of equipment designed for this task, improving cycle time and abolishing systematic downtime due to malfunctions. The operator's safety was also reinforced by the new technical solutions. In addition, the studied of an extrusion process of a component used in the construction of tires was carried out by (Barbosa et al., 2017). By applying the Define, Measure, Analyze, Improve, and Control (DMAIC) methodology and a statistical control of productions. With this methodology, he was able to reduce manufacturing defects, improving quality indices by about 41%. With the implementation of Lean methodologies, (Rosa et al., 2018) was able to improve the production of control cables used for the operation of doors and windows in automobile industry. Through different jobs, the Single-Minute Exchange of Die (SMED) methodologies were applied, The Value Stream Mapping (VSM) analysis was carried out and the application of Standard Work principles were applied. Massive productivity gains were achieved in a product that normally has low added value and labor intensive in its assembly. In addition, (Stadnicka & Litwin, 2019) added VSM analysis to System Dynamics Analysis (SDA) because it was stated that VSM analysis alone was not good enough for the elimination of all wastes in a car production line. The researcher showed that this integration works efficiently. Focusing on the automotive industry, meeting all external requirements that affect the balancing of a production line is relatively difficult as reported by (Sternatz, 2014). He tried to solve this problem and they developed a multi-Hoffmann heuristics of Fleszar and Hindi, improving the best existing procedures so far.

In order to overcome the production lines problems of workload fluctuation, an algorithm capable of combining different balancing techniques was developed by (Fisel et al., 2018). The model consists of distributing the times and tasks along the line based on workload fluctuations. The model allows the manager to make decisions faster on the line balancing and to avoid the arrival of materials to the line that are not yet necessary, thus saving resources. In order to match the feeding of parts with the balancing of the production line, a model was developed by (Nourmohammadi et al., 2018) based on supermarkets to feed the lines, this mode leads to reductions in costs related to the components storage and line balancing.

Rösiö et al. (2019) proposed an assessment criterion of existing manufacturing systems, with a view to analyzing their re-configurability, in order to streamline the response in cases of product change or demand variation. Taking into account the need to advance the productivity of a car air-conditioning systems manufacturing line, they also studied a production line, selected a new pipe folding machine that was integrated in that line, standardized the operations and proceeded to line balancing, thereby increasing the Overall Equipment Efficiency (OEE) by 16%.

2.4. Automotive Program and Its Process Development

The first step of the automobile program is called the conceptual stage, and it is during this stage that design and business strategy concepts are combined based on the desires and demands of the existing market. There are four major divisions in automotive manufacturing as stated by (He (Herman) (Tang, 2017)) which are:

1) Sheet metal stamping;

2) Powertrain manufacturing;

3) Interior/Exterior components fabrication;

4) Vehicle assembly.

The first three divisions are responsible for providing the vehicle assembly plant with the necessary parts, components, and subassemblies. The general assembly (GA) is the division that is responsible for assembling all of these elements into the completed vehicle. According to (He Herman (Tang, 2017)) the three basic automobile assembly activities that are carried out at an assembly factory are the application of body paint, the assembly of the body frame, and general assembly (GA). **Figure 1** illustrates the process flows of vehicle assembly.

The body shop and GA are where the majority of assembly operations take place. High levels of automation are often used at the body-in-white (BIW) assembly stage, whereas hybrid human and machine systems are present during the general assembly (GA) stage.

The development of a new vehicle, often known as the vehicle program, is a challenging project. It's a development initiative with a potential duration of more than three years and an investment budget exceeding millions of dollars

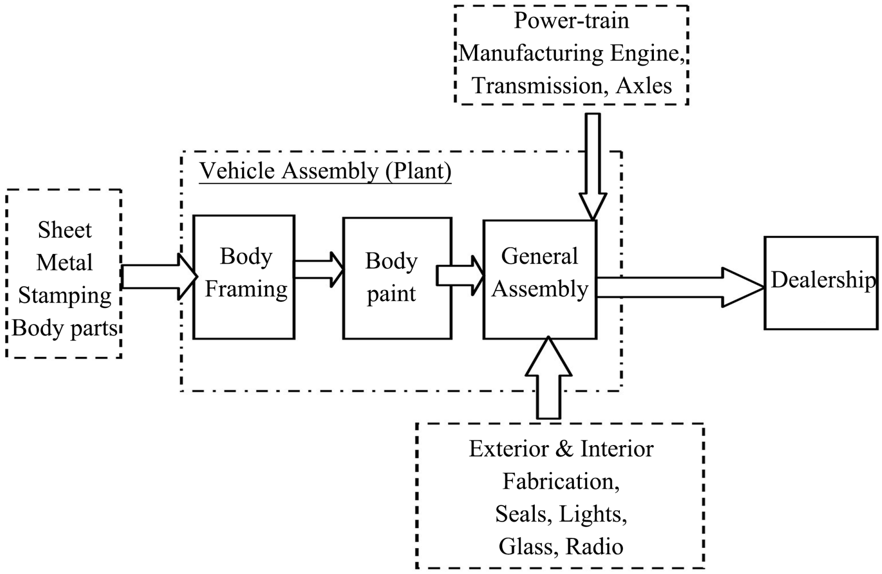

Figure 1. Overall vehicle manufacturing operation (Adopted from He (Herman) (Tang, 2017)).

according to (He (Herman) (Tang, 2017)) and other OEMs. The classification of a vehicle program includes: totally new design, mid-cycle action, and refresh which is based on the levels of engineering and manufacturing changes.

The vehicle development phases for new vehicle are shown in **Figure 2**. The processes involve in vehicle development is almost the same for all automakers. It takes approximately two years for the process to be completed.

During the first three phases of a vehicle development program which are market analysis phase 0, concept creation phase 1, and product engineering phase 2, their development engineers efforts are supported by manufacturing engineering as they evaluate technical restraints, manufacturing capacity, budget, timing, and new technology feasibility.

In the last three phases of 3 to 5, the major efforts of a vehicle program are in manufacturing engineering. The development of manufacturing systems and processes can be further broken down into several tasks, such as process flow creation, system development, process planning, tooling design, and process parameter selections.

In the automotive assembly, typically different vehicles are assembled with the use of the same assembly line called mixed model assembly line (MMAL). The MMALs are characterized by their ability to assemble different models of a given product, without holding large inventories (Kim & Jeong, 2007). One of the main challenges that modern assembly systems are faced with, is the cost-driven demand for faster and more secure ramp-up processes.

The manufacturing system development falls in transition between vehicle product engineering and process planning. The system development sets the framework and transforms the requirement of the product into the overall flows and requirements for all aspects of a manufacturing system. The efforts of the

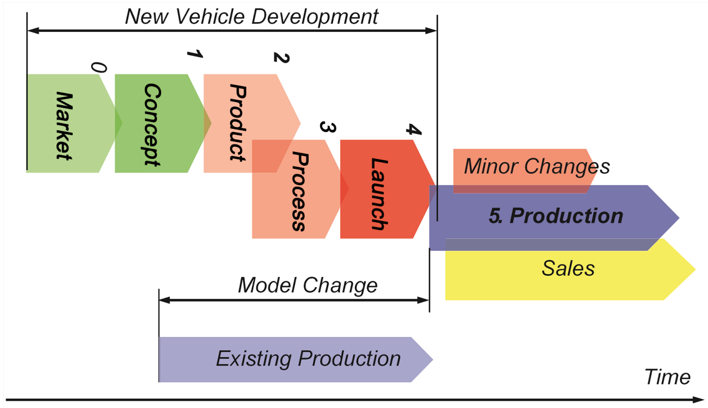

Figure 2. The major phases of vehicle development (adopted from He (Herman) (Tang 2017)).

system development focus on the system capabilities, subsystems and their functionality, system layouts, and interfaces between different process operations. Then the development efforts go to subsystem design. However, the system development focuses on the big picture of manufacturing, while the subsystem development focuses on the individual assembly lines and conveyors (He (Herman), 2017). **Figure 3** shows the effort of the development in the assembly operations at the workstation level, but continues on the process parameters and tooling design.

This goal is however underpinned by the constantly rising number of ramp-ups, due to enhanced innovations and increasing market launches of new products and product variants. The current trend followed by the automotive OEMs, as highlighted by (Bär T, 2008), is the adoption of product, equipment and process standardization.

3. Methodolog

Table 1 is the summary of the methodological choices adopted in this work.

3.1. Materials and Methods

Research Instruments—Questionnaire

Likert Scale

Descriptive Statistics

3.2. Research Design

The descriptive survey design was the primary strategy used to accomplish the goals of this research. In essence, questionnaires, observations, and interviews were used in the study. Most of the questions have a structure. The goal of unstructured inquiries was to gather information unique or particular to the manufacturing/assembly automobile plant in order to support generalizations. There are four sections to the questionnaire (Sections A, B, C and D). The respondents' biographical data is provided in Section A. Section B covers the major study

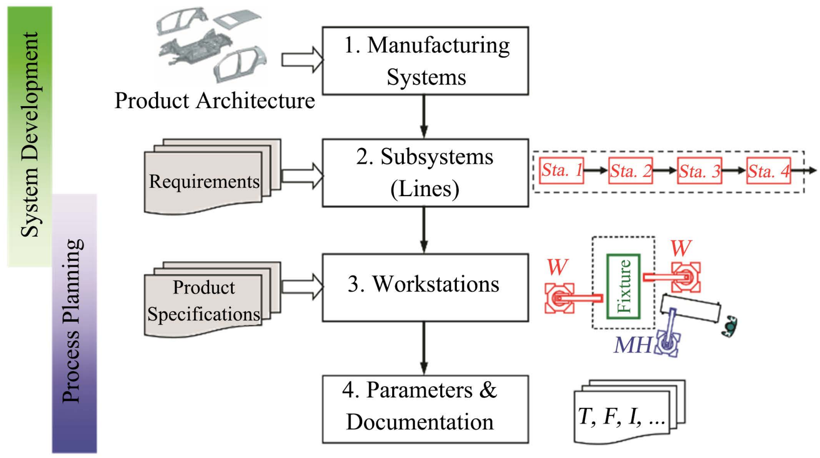

Figure 3. Work focuses of system development and process planning (adopted from He (Herman) (Tang, 2017)).

Table 1. Summary of methodological choices (own illustration).

Methodology	Choice
Research Philosophy & Paradigms	Pragmatism
Research Approach	Deductive approach
Research Design	Qualitative research
Research Purpose	Evaluative research
Research Method	Single case study with holistic approach
Population and Sampling	Non-probability (self-selection sampling) Data
Collection Methods	Questionnaire
Data Analysis Methods	Explanation building and cross-case synthesis
Research Quality	Clarify purpose of interview, chose appropriate location, check data with Participants, cultural reflexivity.
Ethics	Protection of interviewees through Anonymity

questions and information about the respondents' level of understanding of disruptive technologies. Section C consists of statements structured on Likert scale of Strongly Agreed (SA) 5, Agreed (A) 4, Disagreed (D) 3, Strongly Disagreed (SD) 2 and None (1) while Section D is the respondent's general comment.

The criterion mean for the study is given as: $\frac{5+4+3+2+1}{5}=\frac{15}{5}=3.0$.

Three (3) is the criterion mean. The study will accept any item whose weighted mean score (WMS) is equal to or higher than the criterion mean. If not, it will be rejected.

3.3. Population and Sampling

Two major sampling techniques can be distinguished, probability and non-probability sampling. Non-probability sampling is commonly associated with developmental research such as case study research. Due to the case study research that this study employs, non-probability sampling is chosen.

The total population for this study is 60 workers in the welding, assembly and painting section, management and other staff in the manufacturing section of a typical automotive company in Nigeria. This study employ non-probability sampling, more specifically self-selection sampling. This sampling method is very suitable for case study research. Furthermore, this sampling method is easy to realize in practical. Thus, the sample size for this study was determined non-statistically by using a face value evaluation. To this end, 15% of the population (60) was taken as the sample size for this study. Thus 60 copies of the research instrument were distributed in Eight (8) departments in the company. This sample size was selected using the purposive sampling technique. This technique is appropriate for selecting a sample that best represent the population of the study such that individuals who possess better understanding of the research topic were specifically selected for the study.

3.4. Suggested Maturity Model for the Adoption of Industry 4.0

Since the level of maturity of Industry 4.0 adoption is likely to influence the challenges that case company perceive, a model for maturity level has been developed by the author of this study that can be used to categorize the case company. The model is part of the theoretical contribution of this Dissertation and it can be used in the analysis when considering the challenges that companies have experienced at different stages of maturity. Table 2 is the maturity model which integrates different technological concepts and four different levels of maturity into a common maturity model. The four maturity levels are beginner, intermediate, experienced and expert. The level of maturity depends on the state of adoption of Industry 4.0 key technologies. The maturity model in connection with the empirical part provides an overview on the adoption of Industry 4.0 in the manufacturing processes of the respective companies.

3.5. V-Model

The V-model as shown in Figure 4 below will be used for the implementation of the automation in the wedding and painting section from the studies carried out.

V-model is an example of a Predictive Product Development model. This model is mainly used when developing heavily integrated systems, software development, or where test programs are phased with the design. The major focus of the V-Model is to ensure that testing planning and testing activity are aligned to correspond directly with the design activity being performed to obtain a useful and relevant assessment of the changing design. On the left side of the V-Model, it identifies the flow down of the specification of the equipment requirement, workshop layout design, and equipment order activities from the highest level of the section automation down to the lowest level of the component for the intended system; whereas the right side indicates the accompanying

Table 2. Maturity model for the adoption of industry 4.0 in the manufacturing process.

	Level 1 Beginner	Level 2 Intermediate	Level 3 Experience	Level 4 Expert
CPS	Few machine can be controlled through automation	Some machine and system infrastructure can be controlled through automation	Most machine and system infrastructure can be controlled through automation	Machine and systems can be controlled completely through automation
IoT	Machines (and systems) have no M2M capability	Machines (and systems) are to some extent interoperable	Machines (and systems) are partially integrated	Machines (and systems) are fully integrated
Big Data	Data is collected manually when required. e.g. sampling for quality control	Required data is collected digitally and analyze in certain areas	Comprehensive digital data collection and analyze in multiple areas	Comprehensive automated digital data collection and analyze across the entire process
CM	Cloud solution not in use	Initial solution planned for cloud-base software, data storage and data analyses	Pilot solution implemented in some areas of the business	Multiple solution implemented across the business
Robotic	Robot not in use in the factory	One or two activities are being carried out by robot	Some of the major hazardous activities are being carried out by robot	Most of the activities are being carried out by robot.
AR	Augmented Reality glasses or display not in use	Augmented Reality and glasses or display used for small area	Augmented Reality and glasses or display used for some areas	Augmented Reality and glasses or display used for entire process
Smart Factory	CPS, IoT, Big Data, CM, AR and AI not in use	Small part of CPS, IoT, Big Data, CM, AR and AI in use	Some part of CPS, IoT, Big Data, CM, AR and AI in use	All of CPS, IoT, Big Data, CM, AR and AI in use

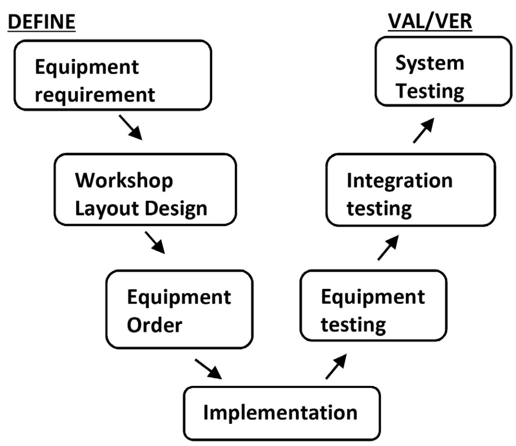

Figure 4. V-model.

test specification and test design activities. Also the right side identifies when the evaluation activities occur that are involved with the execution and testing at various stages of the implementation.

4. Conclusion

This piece contains theoretical contributions in the theoretical framework, as well as in the analysis. Firstly, literature reviews to summarize the adoption of disruptive technology identified by previous research and how the adoption of disruptive technology has transformed the automotive industry. It suggests a maturity model for Industry 4.0 which also depicts a theoretical contribution.

The review contributes to theory by providing an overview on most influential challenges of Industry 4.0 adoption based on the empirical data. Furthermore, the cross-case analysis enabled the investigators to cluster the challenges based on how critical they were seen by the company. This cluster depicts another theoretical contribution of this study.

With regards to managerial implications of this study, it will help managers to achieve an understanding of Industry 4.0 adoption, where is necessary to carry out training of personnel on Industry 4.0. An awareness of these challenges allows managers to react upon them to enable a smoothen adoption of Industry 4.0. This information will be of tremendous assistance to the 58 automotive assembly plants in Nigeria and the National Automotive Design and Development Council (NADDC) in Nigeria. The study has showed that the adoption of Industry 4.0 is achievable, and it can be made easy by beginning the adoption from paint shop and gradually expanding it to other sections of the organization.

Research delimitations and further occurred limitations need to be considered in this research. However, different understandings of the terms used to describe the identified Industry 4.0 depict a limitation. The research focused on the disruptive technology adoption with a focus on manufacturing. This mainly involved welding, assembly line and painting sections as independent departments. Challenges across these departments, such as communication, were not considered in this study. Furthermore, this research focused on manufacturing processes, but other types of business processes in the supply chain were not considered.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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