Automotive Paint Shop Automation in Nigeria

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Abstract - *The automotive industry is currently facing a big challenge for the sustainability of its vehicle production operations and emissions due to economic, marketing, environmental and policy . A study has been carried out in a typical automotive manufacturing company in Nigeria to study their operational practice. In particular, the current level of painting operation and how the painting operation can be automated. A visitation to the automotive painting shop was done for on the spot assessment of their operating system and the level of technology that is currently being applied in the paint shop. It was observed that the automotive paint shop is still operating on human machine kind of painting operation of the vehicle body without the use of robotic system. The robotic system which is one of the disruptive technologies in the industries today of which industry 4.0 is the key enabler is already in full operation in the global key automotive paint shops. The use of robotic painting system comes with a lot of safety in particular health hazard. and other benefit in terms of employability, technology advancement, and increased revenue to the industry. The study shows that if the automotive manufacturing and paint shop in Nigeria being a key player in the Nigeria economy does not want to be left out in the industrial sector, it is now that they start to automate the paint shop by ensuring that robotics systems are in operation in the paint shop.*

Key Words: **Automotive Industry, Industry 4.0, Automation, Painting, Manufacturing, Robot,**

1. INTRODUCTION

In the early years of the automotive industry, the variation in the number of products offered by manufacturers were limited. An example is Henry Ford's policy in 1918, half of all cars in the US were model Ts. In recent time, due to advanced technology, growing market competitiveness, vehicle manufacturers must provide a large product variety to meet customer requirements and this must be done ontime. To meet the demands of the modern market, the factory concept is beginning to change. The traditional industry is transforming into smart digital factories with automation [1]. This is where disruptive technology comes into play.. This goal can be reached by utilizing Virtual Reality. Such an approach enables the testing and validation of system specification, according to requirements, in the early design stages of production plants. In addition, Virtual Reality can give the benefit of a possibility to train staff who are going to work in designed lines before the commissioning.

The present day automotive production plant consists mainly of four shops which are the press shop, the welding shop, the paint shop, and the assembly line, these are usually separated by the buffers [2]. This paper focused on the automation of automotive company in Nigeria. In particular, the paint shop. Methods like V- Model are successfully applied to both body shop and assembly line systems. Fortunately, this is could be an applicable methodology and effective tools to simulate the automated and robotic painting process in the virtual environment. Thus, the operations in the paint shop, which also double as the most hazardous shop in an automotive assembly plant need to be improved in terms of the automation of operations that are currently performed manually, and optimization of the whole process including buffer control system.

The moving assembly line was introduced by Henry Ford in 1914, this introduction was able to reduce production time from 12.5h to 93 min. Every three minutes one car leaves the line and using less man power than previously [3]. The customer had a choice of several types of body work, but the number of available paint colors was limited. Ford wrote in his autobiography that in 1909 in which he told his management team that in the future "Any customer can have a car painted any color that he wants so long as it is black" [4]. However, in the first years of production from 1908 to 1913, the Model T was not available in black [5] but in several colors depending on car's purpose: gray–for town cars, red–for touring cars, and green–for coupes and landaulets (as well as some town and touring cars). By 1912, all cars were being painted midnight blue with black fenders. The one-color concept was finally implemented in 1914. Ford suggested the use of black paint from 1914 to 1926, probably due to the low cost and durability. One hundred years later Ford's color strategy has been replaced by mass customization: the more available colors, the greater the profit. What does it mean for the factory? This section focuses on important problem areas which have been caused by changes in automotive production policy.

1.1 The Ancient Paints

The earliest paints known were found in Europe and Australia [6]. The paint from both Europe and Australia were one-color, others utilized a palette of colors made from natural earthen materials. Most were applied by fingertip but others appear to have been applied with crud brushes made from the frayed tips of soft branches or twigs. These early paints used many naturally occurring color which are red and yellow iron oxides, chalk, charcoal, terra verde, and other variants. The discoveries in the Libyan desert indicate that similar paints were used by the early Egyptians. Their usage led to the development of hieroglyphics which, in turn, led to the Phoenician alphabet. Similar artwork is produced to this day in Central Africa. The Egyptians may have been the first to develop paint in Africa. While they used many natural pigments and materials they appear to be the first to develop synthetic pigments. Egyptian blue was composed of lime, alumina, silica, soda ash and copper oxides. It was made by calcining a mixture of sand, soda and copper. The Egyptians employed a wide variety of organic and inorganic materials as binders: gum arabic, egg white, gelatin, beeswax, etc. In addition, lime, plaster and plaster of Paris were also used. About the same time the Japanese and Chinese were developing their famous lacquer. The base for these lacquers is a latex extracted from a tree known as the 'Urushi' tree in Japan. This tree belongs to the same family of plants as poison ivy and similarly, is quite toxic.

1.2 Historic Development of Car Painting Industry

Following the overall advancement of industrial technology from the beginning of the 20th century until the present, the car painting industry has seen significant changes in the form of materials and processes. During the first half of the 20th century, the early coating procedures required weeks to complete since they required the use of air drying paints, layer-by-layer sanding, and polishing. The entire coating process was carried out by hand.

The most significant turning points in this field were the introduction of mass manufacturing, which required quicker curing paints, higher film performance in terms of corrosion and color endurance, enhanced environmental compatibility, and completely automated processes for increased reliability (Table 1).

With manual application, the number of applied coatings had been lowered to four or five layers (Figure 1). These layers served to protect the primers from corrosion, provide smoothness and chip resistance for the primer surfacers (which are frequently applied in two layers at the front ends and exposed parts), and provide color and weather resistance for the top-coat layer.

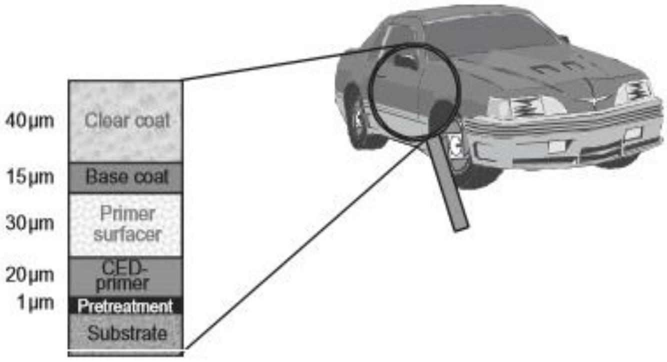

Figure 1 Scheme of the multilayer coating of cars.

Due to the solvent emissions from the solvent-borne paints, the primer application technique was replaced in the 1950s with dip coating, which was more mechanized but also more dangerous. Automobile manufacturers were then required to use either aqueous paints or electrodeposition paints due to explosion and fire risks. The electrodeposition paints, which were first developed in the late 1960s, are more effective in terms of material transfer and throwing power, both of which are crucial for better corrosion protection of the interior of the car body.

Table 1 Milestones and driving forces in the car coating process

Year	Topics/Driving forces	Aspects
1920	Manual painting	Time-consuming process : weeks
1940	Mass production	Enamels/oven/time : day
1970	Improved film performance	CED/2-layer top coat/new materials
1980	Environmental compliance	Waterborne coatings /powder/transfer efficiency
2000	Automated processes	First time capability/time : hours

Due to greater corrosion protection, cathodic coatings swiftly replaced anodic deposition coatings, which were mostly based on salinized polybutadiene resins, in the 1970s. Color and other effects like a metallic finish are created by the base coats. The United States recently saw the introduction of an intriguing technology based on carbamate functioning [7].

Additionally, superior flake pigments made of aluminum and new interference pigments that change color depending on the angle from which they are viewed have been developed as raw materials for the pigment section, which has increased the brilliance and color effects of vehicle coatings.

The technology for coating and painting has advanced, and spray application methods have been significantly improved. Painting craftsmanship is no longer required, thanks to simple pneumatic guns and pressure pots for paint supply. The creation of coating devices, robots, and the current level of automation are the results of a number of reasons. The health danger to the painters who were exposed to solvent emissions from paints in the spray booth and the investment in safety equipment, which is frequently inappropriate for painters, are two of the main causes. The risks associated with the electrostatic application technique are another factor. Another contributing problem was the uneven quality of a manual painting job. The time it takes today for the coating process, including pre-treatment, to finish for a car body leaving the body shop and entering the assembly line can be as short as 8 hours thanks to the latest advancements in wet-on-wet coating technology, coating machines, automated cleaning processes, and modern paints [9].

For coating 10 units per day, modern paint operations require investments ranging from N 25 million to N 2 billion. Today, painting techniques for the automobile industry are largely standardized worldwide. The most common techniques employed today include inorganic pretreatment, cathodic electrodeposition, liquid or powder priming surfacer, liquid base coatings, and one- or two-component solvent-borne transparent coats.

Today, several automakers have chosen to aggressively incorporate environmentally friendly technologies since powder coatings technology has advanced to the point where it is now feasible. Additionally, powder is recognized as the primer surfacer in North America, at Chrylser in all the operational plants, at General Motors (GM) for their truck plants, and in all new paint facilities. Powder is also utilized as a clear coat in a number of BMW facilities in Europe [10].

1.3. Primer Surfacer

The "primer surfacer," also known as primer or surfacer in modern car Original Equipment Manufacturer (OEM) coating, provides the link between the primer coat and top coat. The primer surfacer has a significant selling potential of about 130 000 t per year while having low profit margins given the over 60 million vehicles that are produced annually [11].

There has been establishment of three technologies have now which are stated below:

1. Solventborne primer surfacers
2. Waterborne primer surfacers
3. Powder primer surfacers.

Only solventborne primer surfacers were offered about 20 years ago. The legal restrictions to limit solvent emissions have prompted a progression in the replacement of the solventborne primer surfacer. While powder primer surfacers were introduced in the United States in 2003 with a market share of roughly 26%, aqueous primer surfacers have long been the dominant technique in Europe.

The 1950s saw the adoption of a variety of primers. For instance, a later primer surfacer was employed along with both standard dip coatings and spray primers. Durable corrosion resistance was significantly improved with the introduction of electro-coating for the priming coat. Traditional dip coats were completely replaced by electro-coats. When two-coat finish systems were developed in the middle of the 1980s, the cost savings were seen as indisputable at the time. Additionally, the capabilities of the applied technique have an impact on the base coat's film thickness. Since the electro-coat primer is not ultraviolet (UV) stable or weather-resistant, some chalking and subsequent coat delamination result. Red and mica blue in particular were particularly impacted.

The development of a primer surfacer with zero emission as a UV barrier was driven by volatile organic compound (VOC) rules in the United States, which demand that the emission decrease achieved be maintained in the body shops. The powder primer was the technological advancement that could satisfy this criterion. Chrysler and GM were persuaded by the powder primers' successful technological and environmental fusion. Chrysler was able to draw on knowledge of anti-chip powders, though, even before the debut of this method [12]. Since then, progress has demonstrated that a high level of technological and optical quality is possible. Film thicknesses of up to 250 m can be obtained through powder application, allowing for the replacement of the underbody protection materials in the doorsill area, which is particularly vulnerable to the risk of stone chipping [13].

As aqueous base coatings became more prevalent, the use of waterborne primer surfacers also increased to a standard level. Waterborne primer surfacers have made a big contribution to cutting down on solvent emissions in automotive OEM coating, together with waterborne base coatings. Germany's automotive manufacturing has increased since 1980 by 14%, but since 1990, emissions have decreased by more than 50% [14]. Working together with the coating industry, we were able to accomplish this.

2.0 Automation by Robot

One of the recent disruptive technologies with the greatest potential for use in the automotive production sector is robotics. Most robots up until recently were fairly basic, one-application devices. Only thanks to the quick development of artificial intelligence are robots reaching the potential applications we can currently foresee. Robots are getting brains so they can serve as more than just one-purpose machines with a few axes of motion. Robots can take on a whole new range of issues if they can learn, develop, and think similarly to humans. Robots' reality will change if they can learn from one another and from themselves. Robotics' potential today seems limitless [15]. They are used for a growing number of tasks that go well beyond those on the assembly line. Robots that can read emotions and speak are currently being created. Some robots are evolving to look uncannily like humans as part of this process.

2.1 Painting Robot

An autonomous painting device with six rotatory axes which has three main and three hand axes that is freely programmable and is designed in the bend-arm style is known as a painting robot. A second traveling axis can be added to it. All painting operations on the interior and outside of car bodies can be done with a painting robot. As stated below, the painting robot has six movement axes:

1. Axis 1 (horizontal turning movement of the housing on the basic body)

2. Axis 2 (pivoting movement of arm 1 on the basic body)

3. Axis 3 (pivoting movement of arm 2 at arm 1)

4. Axis 4 (rotatory movement of the hand axis directly at arm 2)

5. Axis 5 (rotatory angularly offset movement of the middle hand axis component)

6. Axis 6 (rotatory movement of the hand axis at the atomizer flange)

The required robot kinematics can be achieved by using arms of various lengths, allowing the robot's operating range to be appropriately adjusted to the painting task [16].

2.2 Common Sensors and Actuators in Automotive Industrial Robots

For industrial robots, sensors are essential. The sensors aid in the detection of the environment and the robot's motion state. The controller will issue the appropriate instructions, causing the robot to carry out the required task with the aid of those instructions. The common sensors used in industrial robots are summarized as follows following a critical review of recent literature:

- **Tactile Sensors -** Industrial robots also require the sense of touch to comprehend their surroundings since tactile perception allows people to perceive many qualities of external objects and interact with their environment flawlessly. Tactile sensors, which are employed in industrial robots that have the ability to feel touch, are therefore essential parts to increase their intelligence. Since they have been developed for many years, tactile sensors are now gradually being used in numerous robots. Capacitive, piezoelectric, piezo-resistive, and optical tactile sensors are the most common varieties [17]. The capacitive tactile sensor measures the contact force by using the change in capacitance. Although it uses little power and has excellent spatial resolution, its interference robustness is subpar [18]. The piezoelectric tactile sensor is based on the idea of the piezoelectric effect, which states that when an external load is applied, an electrical charge will arise on the surface of piezoelectric materials. It has a decent frequency response and a wide measuring range, although its resolution may be better [17]. Although touch sensors are becoming more and more popular, their performance, as well as their adaptability and versatility, is not yet extremely satisfactory. The advancement of numerous technological fields, including materials, electronics, pertinent algorithms, and so forth, is necessary for the development of these sensors [19]. There is still a long way to go before touch sense matches that of a human.

- **Visual Sensors -** In recent years, visual sensing technology has advanced quickly, and today it is widely used in a variety of industries, including face recognition, three-dimensional reconstruction, and numerous robotics, among others. The processor processes visual sensor-captured images to extract information that is helpful for particular applications. Cameras of all varieties, including RGB, multispectral, and depth cameras, are the major type of visual sensor [20]. The photosensitive components found in numerous cameras are often CCD or CMOS, which work on the basis of the photoelectric effect to convert light information into electrical impulses. CCD cameras are more adaptable and produce higher-quality images than CMOS cameras, although CMOS has an advantage over CCD cameras in terms of price and power usage [21].

Diverse information can be obtained from various camera kinds. The most popular forms of RGB cameras are used by people every day to capture chromatic images on the basis of the idea that every sort of visible color can be created using three different shades of red, green, and blue, as well as their combinations. Due to their capacity to capture images in a variety of spectrum bands, including visible and invisible wavelengths, multispectral cameras are able to obtain data that RGB sensors are unable to [20]. Stereo imaging is made possible by depth cameras, which enhance two-dimensional images with distance information. Depending on how they operate, they can be categorized as RGB binocular, structured light, and TOF. Visual sensors are quite popular due to their benefits of being inexpensive, providing a wealth of information, and being simple to use [20]. However, processing visual sensor data is difficult and time-consuming. Despite the numerous algorithms that scholars have proposed, their applicability and adaptability remain unsatisfactory.

- **Laser Sensors -** Since it was developed in the 20th century and possesses exceptional mono-chromaticity, directivity, and brightness [22], lasers are frequently used for a wide range of tasks. The type of sensor known as a laser sensor makes use of laser technology to carry out measurement duties. They typically consist of a measurement circuit, a laser emitter, and a detector. The primary categories of the working material in the emitter are solid, liquid, gas, and semiconductor. Most often, physical factors like distance, velocity, and vibration are measured using laser sensors. The typical varieties include laser range finders, displacement sensors, scanners, trackers, etc. Time of flight (TOF), the triangulation method, and optical interference are the three major types of laser range measuring that can be used [23]. The phenomena of optical interference is the generation of brilliant and dark fringes by superimposing two light beams with different phases. It is used in laser trackers to determine how far a target that has a reflector has traveled. Contactless telemetering using laser sensors is possible, and the speed and accuracy of the measurements are satisfactory [20]. However, because temperature, atmospheric pressure, and air humidity can affect a laser's wavelength, adjustment is necessary when these variables vary.

- **Encoder -** A sensor known as an encoder can convert an angular displacement or velocity into an electrical impulse or a digital number. According to the detecting principles, it can be split into four categories: photoelectric, magnetic, inductive, and capacitive [24]. The most common kind is a photoelectric encoder, which converts signals using the theory of the photoelectric effect. It typically consists of a photoelectric detecting device and an optically coded disc. Photoelectric encoders can be divided into incremental and absolute encoders based on the calibration mode of the coded disc.

Square wave pluses are the result of incremental photoelectric encoders. The amount of the pluses can be used to calculate the rotation angle, and a zero-reference location is necessary to ascertain the rotating shaft's absolute position. Absolute photoelectric encoders can obtain the absolute position immediately because they produce the binary digital quantity that corresponds to each location of the axis. Due to its benefits of compactness, longevity, usability, and established technology, encoders have been extensively utilized for many years [25]. The number of scribed lines on the coded disc in a single circle determines the resolution of encoders. More lines can be used to differentiate smaller angles, which results in increased resolution but also higher expense.

- **Other Sensors -** In addition to the four sensor types mentioned above, other sensors, such as proximity sensors, inertial sensors, torque sensors, acoustic sensors, magnetic sensors, ultrasonic sensors, etc., are also used in industrial robots to carry out various tasks. An example of a non-contact device that may detect approaching objects and produce analogous switching signals is a proximity sensor. Based on the foundations of functioning, it can be divided into capacitive, inductive, and photoelectric types [26]. Capacitive proximity sensors use the change in circuit status brought on by the detecting electrode's capacity variation to detect things that are getting closer. To function, inductive proximity sensors rely on electromagnetic induction. The detecting coils are the sensing components of them, and when a metallic conductor approaches, their inductance will change. They are frequently used to gauge the acceleration, angular speed, and azimuthal angle of moving objects. The inertial measurement unit (IMU) is the term for their triaxial combination. Dead reckoning (DR), which uses the integration method to determine how much an object is moving, is the underlying measurement principle of inertial sensors. Inertial sensors have quick, pleasing precision, but over time, the inaccuracy will grow [26].

- **Torque sensors** – These are mostly employed to gauge the torque applied to shafts or mechanical power transmission systems. The inductive torque sensor and the resistance strain torque sensor are the two most popular varieties. They often have a torsion bar as well as sensing components like coils or resistance strain gauges. Torsion bars connect the input and output shafts. Torsion bar torsional deformation brought on by a torque can be converted into electric signals by varying the parameters of the detecting elements, allowing for the realization of torque measurement. Sound waves can be converted into electric signals using acoustic sensors. They have a capacitive electret microphone fitted, and sound waves can cause the electret membrane in the microphone to vibrate. This causes a variation in capacity and produces weak voltage. After that, the voltage is converted for further use. The basic purpose of magnetic sensors is to measure magnetic field strength. The Hall Effect serves as the basis for operation. This phenomenon occurs when electricity flows through a conductor and creates an electric field that is perpendicular to the direction of the magnetic field. This creates a potential difference on the conductor's surface.

Obstacle detection frequently makes use of ultrasonic sensors. According to the amount of time it takes to emit ultrasonic waves and receive echoes, they determine the distance between objects. They are inexpensive, have a low cost and power consumption, and are compact in size and weight [27]. Industrial robots are multipurpose manipulators that can be reprogrammed to carry out a variety of tasks, according to [28]. An industrial robot's essential parts are its manipulator, controller, and teach pendant. A robot's user interface, which resembles a computer display and keyboard, is its teach pendant. Robots can be classified into six types based on their coordinates and kinematics, and Table 2 lists each type's properties.

Table 2: The Characteristics of the Types of Robot

Coordinate	Features
Cartesian	The arm has three prismatic joints, whose axes are coincident with a Cartesian coordinator. Arm has linear X, Y, and Z motions
Cylindrical	The arm moves along the Y and Z axes. Robot can rotate around the base (a cylindrical coordinate system), normally has 3 DOFs
Spherical/polar	The arm has one sliding and two rotational motions, a polar coordinate system
SCARA (selective compliance assemble. Arm	Two parallel rotary joints to provide compliance in a plane. The horizontal arm has three axes
Articulated	The arm has multiple rotary joints. The arm can reach any part in its working envelope
Parallel	Arms have concurrent prismatic or rotary joints.

The kinematic needs of applications determine the sorts of robots that can be used in production. Cartesian and cylindrical kinds can be utilized for simple movements like painting a car. In automotive assembly processes like welding, sealing, and MH, articulated robots are frequently utilized.

Different degrees of freedom (DOFs) may be present in a robot. A robot's joints and axes each introduce a DOF. The robot needs three axes in order to travel anywhere in space. As seen in Figure 3, articulated robots have three rotational axes (roll, pitch, and yaw) that they can use to determine how the arm's tip is oriented. For instance, handling instruments like arc welding is a popular task for 5-DOF robots. If necessary, a sixth axis (or joint) can be added.

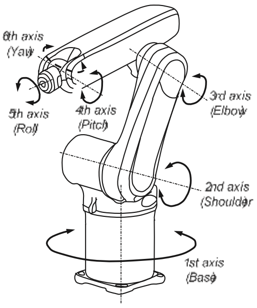

Figure 3 An articulated robot and its DOF

A sensor is a device to detect a physical object or variable, such as the existence, position, force, and speed, according to [28]. Transducers and encoders are both frequently employed sensors. Transducers transform physical variables into more useful forms of data, such voltage, for automation. Encoders send information signals by combining sensor-analyzer operations.

2.3 Paint Shop Design and Quality Concepts

One of the most intricate production processes in the car industry is the paint shop. The highest standards are set at the paint shop for the processes' environmental friendliness, productivity of the painting installations, and functional and aesthetic quality of the painting. These are to blame for the high level of automation present in vehicle painting facilities.

A typical coating line is around 300 meters long and can paint 10 units per hour. A body's dwell duration ranges from 6 to 11 hours. A completely automated paint shop employs between 10 to 30 employees per shift, primarily for maintenance, process control, and troubleshooting. Both value-adding and non-value-adding scopes of work are present in the process chain. Manual labor-intensive tasks like sanding, polishing, cleaning, smoothing, and repainting are examples of non-value-adding tasks. The ultimate abolition of non-value-adding occupations or at least their reduction to the absolute lowest number is a future goal. Value-adding procedures are currently highly automated, and full automation is anticipated in the future [29].

The aim to lower the cost per unit (CPU) is a reflection of the mounting demand to cut costs. All Original Equipment Manufacturers (OEMs) have been using the same standard painting procedure for many years, and it entails the processes of primer, basecoat 1, basecoat 2, and clear coat. Consolidated techniques are currently being launched, which have quicker process times and either do away with the primer application or apply all coatings wet-on-wet without any drying in between. The field of surface coating technology is undergoing significant changes. Cost reduction, environmental compliance, and increased quality are the evident goals here [30].

2.4 General Layout

The manufacturing line layout in the paint shop has changed over time. In a paint shop, the various process steps are often organized across several levels of the structure. The pretreatment dipping tanks are on the lower level. The spray booths and work decks are located on the level above that. The automobile body storage space and dryers located on the floor above this one. On the top floor, in the so-called pent house, are the air-supply units.

Clean room design is frequently used to create installation areas, such as the primer and top coat area, where cleanliness is crucial. After a thorough washing, the automobile bodies are brought into this location. It is prohibited to enter this region and particular attire is required [31].

Dry or moist procedures can be used to automatically clean the body's surface. The procedure has two parts in each situation. To remove dirt particles that may have been integrated into the surface, primarily during pneumatic-spray treatments, the interior portions and seams are blasted out in the first stage. The body is pumped via a device that has air nozzles directed in the horizontal, vertical, and other directions at a rate of more than 40 m s1.

The airstreams carry the dirt specks to the edge of the zone, where filtering equipment traps them. The clean air is recycled and used to refuel the nozzles after filtering. The body surface is cleaned in the second step using rotating rollers that have feathers attached to them. The feathers gather the dust that is drawn away from the rollers. The rollers have programmed rotational speeds and are spaced apart from the body surfaces. Simple washing is another approach for cleaning the surface of the body. In this instance, the body is either washed with high-pressure water jets or dipped and treated with revolving brushes, much like a washing station. The high-pressure water jets clean out the dirt in the inner portions. Robots are used to steer the nozzles in the proper direction for the greatest outcomes.

Short lead times, straight-line material flow, compact, space-saving design, consistent implementation of dust-protection measures, concentration of installation technology and work decks, short and easy access for operating and service personnel, and simplified maintenance and service conditions must all be met for a layout to be considered optimal.

Ergonomics studies can be undertaken, and simulations of the material flow or the robot stations can be included. Finally, a variety of virtual reality technologies allow for the inspection of the paint shop [32].

2.5 Automation in the Paint Application

Fully automated paint application has gone through a number of stages of development. Machines were used to paint the automobile bodies' outside surfaces in the first stages. The robot concept evolved from the machine concept. This change was motivated by the need for greater flexibility and efficiency.

Therefore, robotic installations offer greater freedom for vehicle design and painting tasks. The high-speed rotating atomizer is currently replacing the pneumatic atomizer for the second metallic application. In the future, exterior painting will most likely be accomplished using the bell-bell application using robots. Fully automatic interior painting, a field of robot technology that has always existed, has moved away from pneumatic application during the past few years. The most recent level of advancement as of yet is interior application with rotating atomization [33].

For robot painting, there are two distinct methods of moving or transporting the body, although they share some characteristics. Painting in tracking is the first approach, which involves moving continuously through the robot station. Painting in the stop-and-go method is the second. In order to fix and position the body for the robots, the latter requires a quick drive into the robot station.

3.0 V- Model

The V-model will be used for the implementation of the automation in the painting section as discovered by the researcher.

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 emerging 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. The right side indicates the accompanying 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.

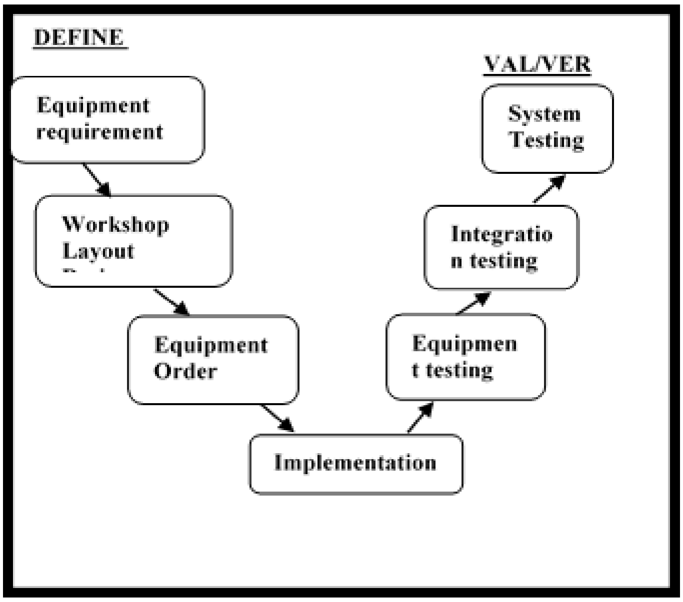

Figure 2 V-Model

3.1 Proposed Automated Work Flow in the Body Paint Shop

In the paint shop, there are series of processing steps which are performed to prepare and coat the car body surfaces. These steps are: (1) phosphate, (2) electro-coat, (3) sealer, (4) prime, (5) base coat, and (6) clear coat. The phosphate process chemically cleans the surface and treat the surface so as to prepares it to accept the paint coat. The electro-coat is for corrosion protection, edge coverage uniform film and paint reduction. The sealant is applied for noise, vibration and harshness (NVH), preventing water leakage and corrosion. The priming operation adds the first coat of paint. Base coating is the coat that provides the specific color to the automobile vehicle body. The clear coat is applied for good appearance and complete the coating process for durability. The paint shop should be organized into six sections, corresponding to these steps. Between the sections, there are drying and cooling areas. Figure 4 presents the organization of work in the department.

The phosphate operation is a fully automated dipping process which is a chemical treatment process in which the body handler, with vehicle bodies on board, are submerged in a large tank of chemical solution to prepare the body for painting. The dipping tank is long and wide to accommodate the super structure. The vehicle bodies are moved through the tanks by continuously moving conveyor. Immediately after phosphate coating is the e-coating. The E-coating uses electrodeposition principle to apply a primer coat layer on top of the phosphate layer, this is done by immersing the vehicle body into an E-coat tank. This is also a fully automated operation. After this operation, the body is moved into the oven for cure and for optimum durability. After E-coat, the next process is sealing. The sealing process is applied to cover the welds and edges of vehicle bodies. After this is the application of primer. The primer is usually powdered based. This powder process required no solvents, and the powder coating is usually preferred than liquid primer for primer operation. Although automated, phosphate, E-coat and primer each require man crew for maintenance and monitoring. These crews are included in the direct labor hours per vehicle allocated to the paint shop.

Following primer is an enclosed drying oven which must permit a total of 15 minutes average drying time for each vehicle body as it goes through the oven. The drying oven is wide and large to accommodate the vehicle body. Another 10 minutes must be allowed for the bodies to cool before going into the base coat line. The base coat line is a ventilated paint line consisting of a combination of robots and humans to perform the color base coat. An average of ten minutes are then provided for the base coat to dry before going into the clear coat line.

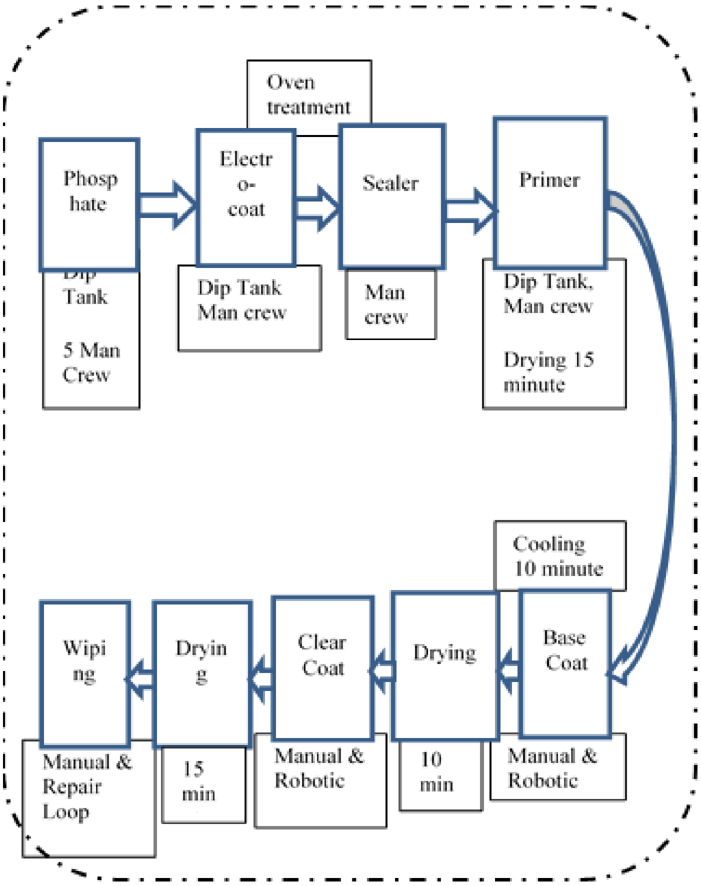

Figure 3 The Proposed Automated Work Flow in the Body Paint Shop

After clear coat, the vehicle body is allowed to dry for about 15 minutes. The paint drying areas in the plant should be adequate enough for the various operations. This is followed by a series of workstations in which the bodies are manually wiped, buffed, and inspected for painting flaws.

There could be defect in the paint shop, and when this happens gthose vehicle bodies needing repair will be transferred to the repair area and are then sent back into the line before exiting the paint shop. Painted vehicle bodies with defects are simply taken off the regular line, repaired, and then returned back onto the line at vacancies where other vehicles might have been removed for repair. The balance delay and other line factors in the paint shop include the effect of the expected workload in the repair loop.

During the implementation of this project at the automotive manufacturing/assembly plant, the average balance delay will be calculated not counting phosphate and primer and the average manning level will be found on the paint shop workstations. Repositioning time should also be calculated. The balance delay and manning level will include the effect of the robotic stations. The paint department should be planned for a line efficiency (proportion uptime) of 95%. Each station in this department should be long and wide enough to accommodate the operation.

4.0 CONCLUSIONS

This research and development contains theoretical contributions in the theoretical framework, as well as in the analysis. Firstly a thorough literature review was conducted to summarize the automation of the paint shop of the automotive industry in Nigeria. In addition, visitation to local OEM was conducted for on the site assessment. A V-model for the implementation of this automation in the paint shop which also depicts a theoretical contribution was designed by the investigatoror

The analysis contributes to existing theory by providing an overview on most influential challenges of automotive industrial paint shop automation based on the empirical data. Furthermore, the cross-case analysis enabled this researcher 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 research work it can be said that the findings will help managers to achieve an understanding of paint shop automation in Nigeria. Awareness of these challenges allows managers to react upon them to enable a smooth transition from human machine paint shop currently in use across the nation to automated paint shop.Therefore, it can be summarized that the findings of this research work support managers in the decision step of the automation adoption process. Overall, it can be said that this work contains valuable theoretical contributions as well as managerial implications.

The authors can acknowledge any person/authorities in this section. This is not mandatory.

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