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Chapter

Application of the Fourth Industrial Revolution for High Volume Production in the Rail Car Industry

Daniyan Ilesanmi, Oyesola Moses, Mpofu Khumbulani and Nwankwo Samuel

Abstract

Some recent technological advances in line with the fourth industrial revolution (4IR) are rapidly transforming the industrial sector. This work explores the prospect of robotic and additive manufacturing solutions for mass production in the rail industry. It proposes a dual arm, 12-axis welding robot with advance sensors, camera, and algorithm as well as intelligent control system. The computer-aided design (CAD) of the robotic system was done in the Solidworks 2017 environment and simulated using the adaptive neuro-fuzzy interference system (ANFIS) in order to determine the kinematic motion of the robotic arm and the angles of joint. The simulation results showed the smooth motion of the robot and its suitability to carry out the welding operations for mass production of components during rail car manufacturing. In addition, the ability to fabricate several physical models directly from digital data through additive manufacturing (AM) is a key factor to ensuring rapid product development cycle. Given that AM is embedded in a digitally connected environment, flow of information as well as data processing and transmission in real time will be useful for massive turnout during mass production.

Keywords: 4IR, additive manufacturing, kinematics, robotic solution, simulation

1. Introduction

Previous industrial revolutions have given birth to various breakthroughs in the rail industry ranging from the development of trains powered by diesel to electric. In recent times, the advent of the fourth industrial revolution (4IR) and robust digital solutions have produced advance technology for manufacturing. As shown in **Figure 1**, this innovative advances in manufacturing relates to automation and robotics [1, 2], Additive Manufacturing (AM) including subsets like 3D printing, Rapid Prototyping, Direct Digital Manufacturing [3, 4], Cyber-physical systems (CPS) [5], Physical Internet (PI) and Internet of Things (IoT) in the logistics and transportation area [6, 7] as well as artificial intelligence (AI), augmented reality,

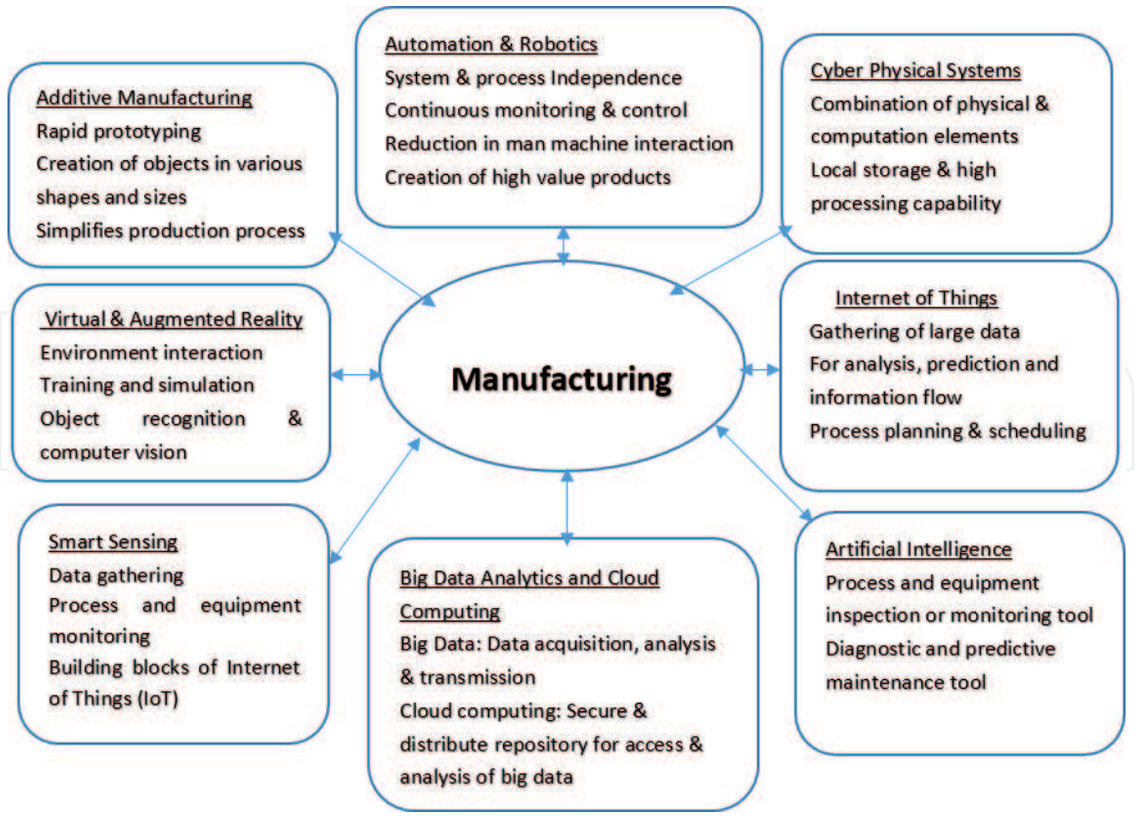


Figure 1.
Elements of the fourth industrial revolution relating to manufacturing.

big data analytics and digital solutions in the informatics field [8, 9]. Many industries are now embracing the fourth industrial revolution known as Industry 4.0 amidst dynamic production challenges and increasing market forces. For instance, artificial intelligence (AI) find applications in process planning and optimization, robotic development, decision making, system control as well as pattern recognition involving automatic incident detection, image processing for traffic data collection and for identifying cracks in rail structures [10, 11]. In the same vein, artificial intelligence can also be explored in rail car manufacturing for nonlinear prediction relating to traffic demand, the deterioration of rail infrastructure as a function of traffic, construction, and environmental factors. In addition, the quest for smart, high volume and intelligence systems is a major driver that propels manufacturers' into the development of new production technologies, which incorporates the concept of the FIR.

The aim of these technological advances in the manufacturing sector is to increase productivity, promote automation and control and enhance good product quality and conformity to standards. This will increase equipment reliability and availability thereby making the supply chain, assembly and production lines smarter. These have also brought about a tremendous growth and innovation potential for global value chain setups. These manufacturing technologies are enhancing high rates of production at an effective unit cost. One of the advantages of high volume production is that costs are expected to reduce as the volume of production increases.

This work focuses on the application of the Fourth Industrial Revolution (4IR) characterised by emerging robotic solutions with smart monitoring system and the exploration of additive manufacturing for rapid prototyping during assembly operations in the rail car industry. The use of monitoring systems will help in diagnosing and tracking the technical conditions during the assembly operation of the rail car using the online mode (in real time) in order to obtain the system

and measurement performance [12–14]. The rail car manufacturers are increasingly testing the potential of additive manufacturing (AM) to break creative barriers within the three major trends driving the industry namely; product innovation, high-volume direct manufacturing and fuel efficiency with increased performance [15, 16]. The complexity and intersecting technologies driving the fourth industrial revolution and the breadth of their impact necessitates the development of innovative approaches to implement and diffuse the current and emerging technologies for rail car development. The concept of mass production involves the development of tools and automated equipment for the production of interchangeable parts and products in order to strike the right balance among cost, quality and quantity.

The merit of mass production systems include the development of large products to a high degree of surface finish and precision, significant reduction in the cost of labour due to the automated nature of the assembly line and resultant reduction in the overall production cost. The effective production control and monitoring can increase process improvement with good information flow with data acquisition and management systems. This fast rate of production will enable prompt scheduling, realistic forecast and product distribution with overall increase in profitability. Although, the initial set up of mass production lines is energy and cost intensive but the initial cost are often offset as the business breaks even over time due to profit from high volume production. The major drawbacks of the mass production systems include; the replacement of personnel with automated systems and the fact that the system is relatively inflexible to production changes, which are integral part of the production processes.

2. The developmental framework

The fourth industrial revolution provides solutions for many complex problems in the rail industry. If adequately deployed, it has the potential to revolutionise the assembly and operation of rail car systems, leading to transformation in the development, operation and maintenance. This will deliver benefits to the rail industry and users as well as the wider economy, including innovative approach, increased capacity, improved performance and enhanced safety for passengers and workers. This means that while the rail industry will be able to save cost considerably at increased efficiency and delivery, the operational activities and maintenance will be more reliable and effective. The developed framework for rail car development with the inclusion of supply chain activities is presented in **Figure 2**.

The part manufacturer uses innovative material based solutions for parts development while the component manufacturers develops the parts into components which is supplied to the sub assembly manufacturer. The sub assembly manufacturer integrates different components into a sub assembly unit and develops a feasible framework for prototyping. The original equipment manufacturer (OEM) does the final assembly of various sub-systems into a system while the Information Communication technology unit (ICT) and logistics facilitates the supply chain relationships in order to keep the stakeholders abreast of advances in technology, demand and supply as well as planning and production. Some of the materials employed for the rail car manufacturing as well as the component parts developed into subassembly and final assembly are listed as follows:

a. Materials: Aluminium, fabrics, stainless steel, steel, rubber, plastic, glass, carbon fibre etc.

b. Component parts: Compressor, brake parts, blower, cable, controls, indicators, rectifiers, inverters, carbon fibre etc. gears, sensors, printed circuit boards, bolsters, runners, bars etc.

c. Sub assembly: Mechanical: Wheelset, suspension system, bogie, brake, engine, body side, underframe, roof, body shell etc.

d. Electrical/electronic: Communication, security, power, integrated software etc.

e. System: Rail car, rolling stock, rail track, control unit

In order to maximise the benefits of the advanced manufacturing technologies, the perceived industrial key players can develop the theory driving the elements of the new industrial revolution into practical knowledge as stated in the following subsections.

2.1 Welding operation in rail car assembly

Welding is one of the methods usually employed for joining the components parts during rail car development. It is a complex manufacturing process, which requires the combination of a number of different factors such as material metallurgy, process parameters, welding sequence, power source, energy, speed, filler materials as well as the material combination and thickness for the design of an efficient process. Hence, an optimised welding process will bring about the development of reliable weld joints and shorter welding cycles via efficient process development.

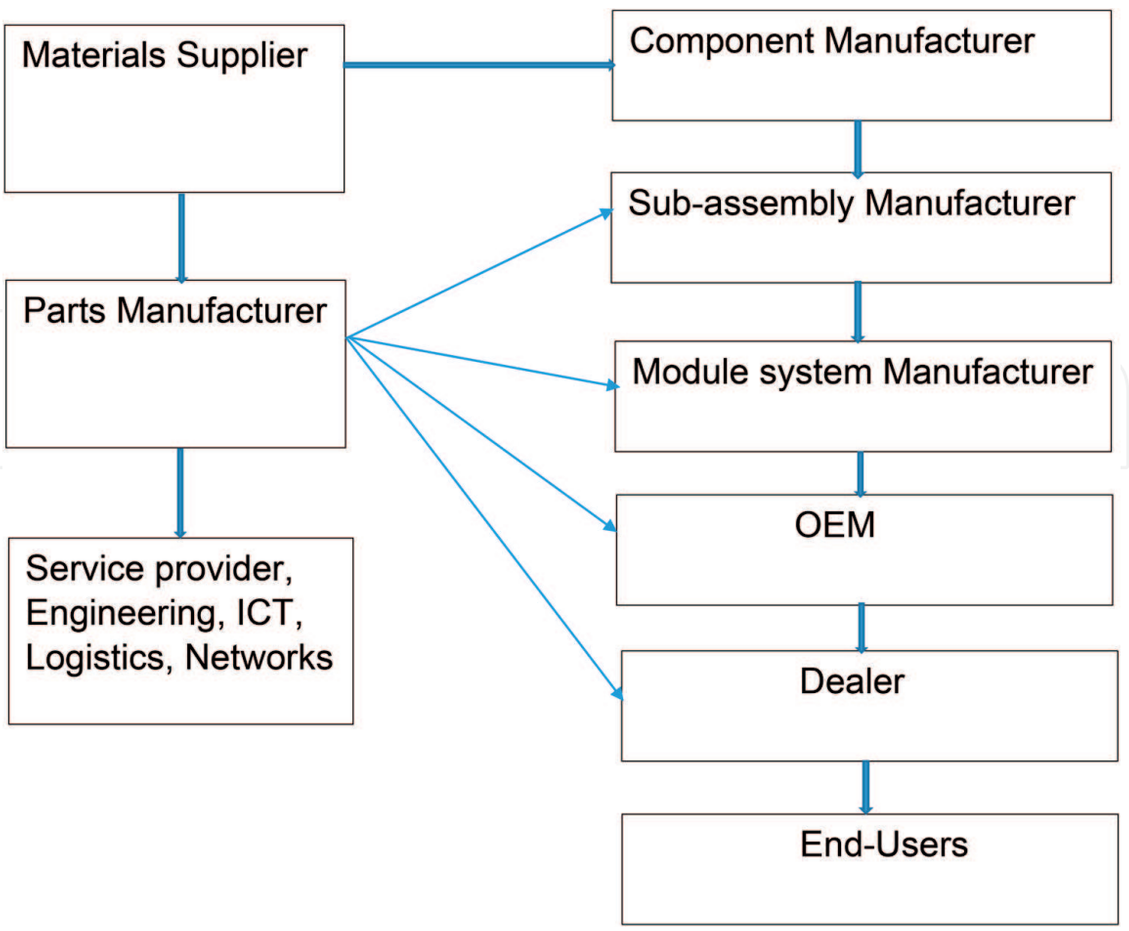


Figure 2.
The framework for rail car development and supply chain activities.

The welding operation is usually employed for the assembly operations in the underframe, body side, side panel, bogie frame and roof among others. The underframe, which is the part of the body shell, has parts, which includes the bars, runners, bolsters etc. The upper and lower brackets are usually welded on to the underframe through arc welding while the friction stir welding (FSW), resistance spot welding (RSW), metal inert gas (MIG) or laser arc welding (LAW) are usually employed for joining the body side. The body sides are made from high strength stainless steel or light aluminium materials that are welded on a frame. The body shells are first welded before the fitting operations and the windows are either cut out of the body side panels or the sides assembled in sections through the pre-installed window frames. Furthermore, the side panel are welded on to the frame of the body side. The welding process is also employed in the joining of the roof with specialised contour-shaped jigs, which holds the roof for welding operations, and ceiling installations. The bogie frame is also fabricated via welding operation before the assembly of the suspension systems. Different welding methods are employed for all the aforementioned processes depending on the design and performance requirements.

2.2 Robotic solution for mass production

A robot is a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or specialised devices, to variable programmed motions for the performance of a variety of tasks [17]. Robotic solutions for the assembly, maintenance and repair applications in the rail car and transit coaches is essential for performing activities such as welding, grinding, cleaning, and painting due to increasing complexities, repetitive, and high volume production requirement. Other advantages of the use of robots for assembly operations include; automation via less human involvement, increased precision and productivity, consistent weld penetration resulting in better quality and surface finish, safety, improved product quality, reduction in assembly interruptions, flexibility and reduced labour costs. This work proposes a dual arm, 12-axis welding robot with advance sensors, camera and algorithm as well as intelligent control system. It also has robotic manipulator with an end-effector for gripping, positioning and welding of various component parts during rail car manufacturing. The smart sensors, which are the basic building blocks of the Internet of Things (IoT), are incorporated for data collection to enhance the process condition and real time monitoring, diagnosis and efficient communication. A large amount of data gathered through the smart sensors and IoT for are often suitable for the analysis and development of predictive algorithm. The automation of the welding process via effective communication and intelligent coordination will improve the overall efficiency and safety of the assembly process. This will decrease the failure rate, interruptions, and enhance the reliability of manufacturing and maintenance activities. The dual arm is to allow multiple task to be carried out in order to reduce the assembly time with increase in the production rate while the sensors and intelligent control system are to monitor and provide necessary feedbacks relating to weld imperfections and quality. This will lead to significant reduction in the welding cycle time with higher deposition rate and consistent weld penetration. Since the overall production cost is partly a function of the welding cycle time and the production rates, the use of the dual arm-welding robot will bring about significant reduction in the overall production cost. Another advantage is that there will be significant reduction in the welding error and expensive rework due to less human involvement, leading to the production of assembly that meets design and customer's requirements. In addition, the choice of automated dual arm robot will sufficient address the issue of monotonous repetitive task as well as other safety and ergonomic issues relating to assembly operations in complex geometries as opposed to manual assembly lines. Depending on the type of

assembly operations to be performed, the essential factors to be considered for the robotic configurations and selection include the degree of freedom, space geometry, motion characteristics as well as drive and feedback mechanism. In addition, with the process parameters specified and programmed in real time, the robot simply emulate the manual welding process by following a specified or desired trajectory to track the seam geometry and perform the welding operation. This is followed by the post weld assessment with the use of sensors and 3D cameras for the assessment of the weld integrity. The deployment of robotic solutions however is not without challenges. The use of robots for welding requires proper configuration and joint design with consistent gap conditions as variations may lead to time wasting and expensive rework. In addition, robotic welding sometimes is limited by workspace constraints and the need for sensors and intelligent systems for effective monitoring and control. In addition, robots cannot independently make corrective decisions because they are programmed.

Figure 3 shows the flowchart for the robotic assisted welding.

The design considerations for the robotic arm include the size of the component parts or sub assembly, welding method, welding cycle time, process parameters and repeatability. The robot is designed to move the welding torch along the weld path given the direction of motion and speed as programmed. To control the orientation of the end of the arm, the yaw, pitch and roll axes are added to the other X, Y, and Z axes to make 6 axes for each of the arm.

The specification of the designed dual arm robot is presented in **Table 1**.

For high volume production, the robot can be programmed with set of codes and instructions for the complete welding process and operation following the determination of the weld location, creation of robotic path and setting the process parameters and torch angle. The controller sends signals to the drivers and motors via computer programmes for the execution of the welding operation while the manipulator positions the component parts so that it could be easily accessed and worked upon by the robot. The CAD of the dual arm-welding robot and its exploded are shown in **Figures 4** and **5** respectively.

For increased flexibility and productivity in a mass production setting, the robot is designed such that it can be mounted on a column in order to carry out welding

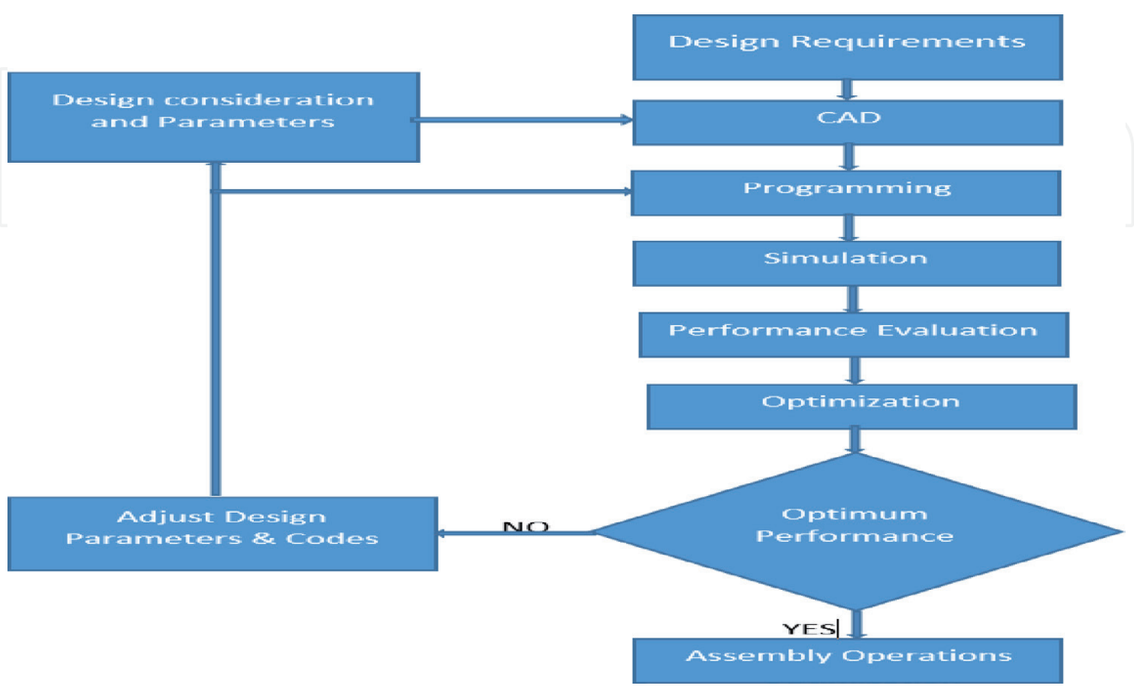
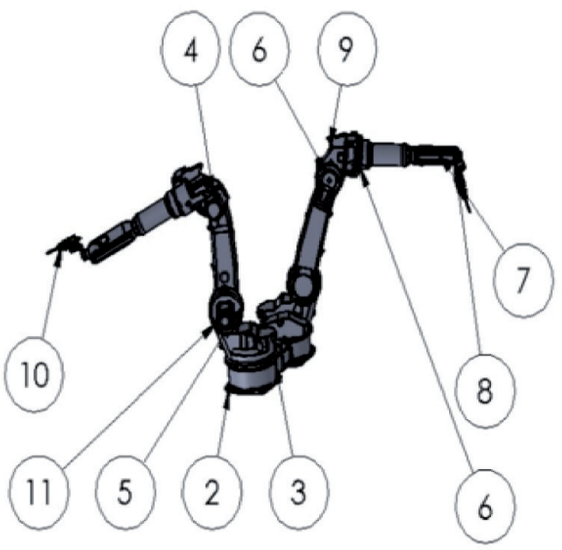


Figure 3.
The flowchart for the robotic assisted welding.

S/N	Parameter	Value
1.	Reach height	3 m (Max.)
2.	Repeatability	0.0001 m (Max.)
3.	Velocity	6 m/s (Max.)
4.	Weight	400 kg
5.	Payload	500 kg
6.	Degree of freedom (DoF)	12

Table 1.
The specification of the designed dual arm robot.



Item No	Part	Quantity
1.	The dual arm robot	1
2.	Base connector	1
3.	General control module	2
4.	Elbow motor	2
5.	Shoulder motor	2
6.	Elbow control module	2
7.	End effector gripper	2
8.	End effector with soldering led	2
9.	End effector gripper motor	2
10.	Electrode holder	2
11.	Shoulder motor	2

Figure 4.
The CAD of the dual arm robot.



Figure 5.
The exploded view.

operations of complex geometries. In such instance, the work piece is clamped and kept stationary while the robot approaches it for welding operation. This will eliminate the idle as well as loading and unloading time. In order to ensure an efficient performance of the robot, the motion of the robot was simulated using the adaptive neuro-fuzzy interference system (ANFIS) modelling which comprises of a fuzzy system whose parameters are fine-tuned using the neuro adaptive learning (NAL)

method. The essence of the modelling and simulation is to determine the kinematic motion of the robotic arm. The understanding of the kinematics will ensure the determination of the motion of robot, angles of the joint and arrangement of location of the tip of the arm at the desired position (**Figure 6**).

The predicted angles of joint for the robot are shown in **Figure 7**. The angle determines the rotation of the robot in the predetermined directions. **Figure 7** indicates that the robot can rotate in both the clockwise and the clockwise directions with various angles corresponding to $0° < \omega < 450°$ which the robot might be required to turn.

Most welding robots function semiautonomously. In order to function optimally most especially during assembly operations such as welding, there is need for the development of specialised jigs and fixtures for easy and accurate location, position and clamping of the component work piece. The production of components in mass depends upon the interchangeability that facilitates easy assembly. Mass production methods require fast and relatively simple method of work positioning for accurate operations. Specialised jigs are devices often employed to hold, support, guide and locate a work piece during manufacturing operations. For components or subassemblies produced in mass, the use of jigs saves machining time by eliminating the task of marking out, repetitive check or work set up, measuring and other set up before machining. With the automatic location of work piece, the assembly operation is carried out with high degree of precision and accuracy. The development of specialised but flexible jigs facilitates mass production with the simultaneous operation of different tools in a single set up thereby reducing the handling time. Hence, the use of assembly robot with specialised jigs will also reduce the overall labour and consequent fatigue as the handling operation and time is simplified and minimised. To a large extent, it saves labour cost and the overall cost of machining. The only limitation is that inaccurate location and clamping by the fixturing elements may cause variations in the dimensions of the work piece resulting in weld imperfections or distortions. However, this challenge can be solved with the use of advance sensor and intelligent systems for weld monitoring and control. The assembly of the rail car body requires the use of jigs to ensure rigid clamping and right position of the work piece during the assembly operations. The jigs are designed for specific purpose after the design of the rail car body and its specifications. Conventional jigs are not flexible enough to permit changes of work piece during machining operations. The rigidity of the conventional fixtures often reduces the volume of production, accuracy of surface finish while also increasing production time and cost. Jigs are reconfigured to provide an effective mix of flexible and dedicated equipment which is expandable and whose functionality and productivity can readily be changed

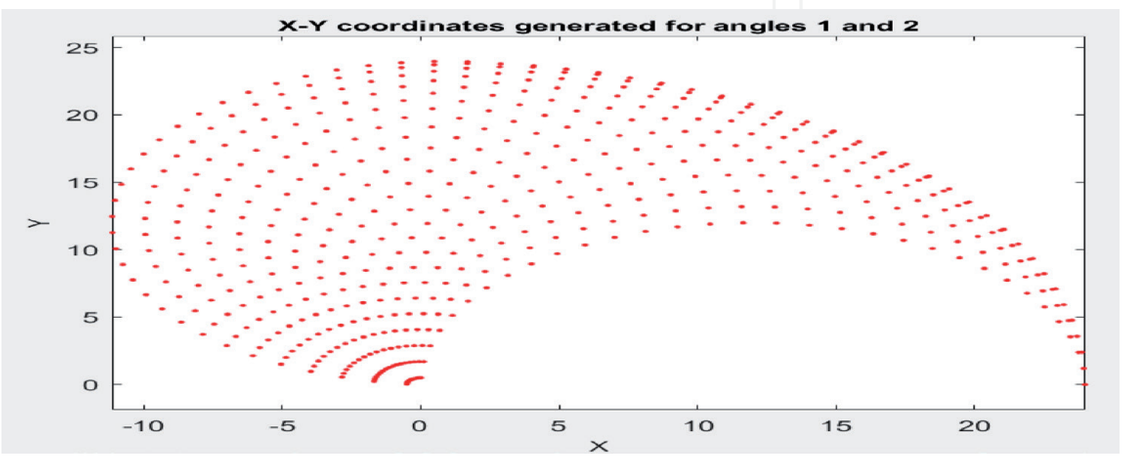


Figure 6.
Kinematic motion of the robotic arm.

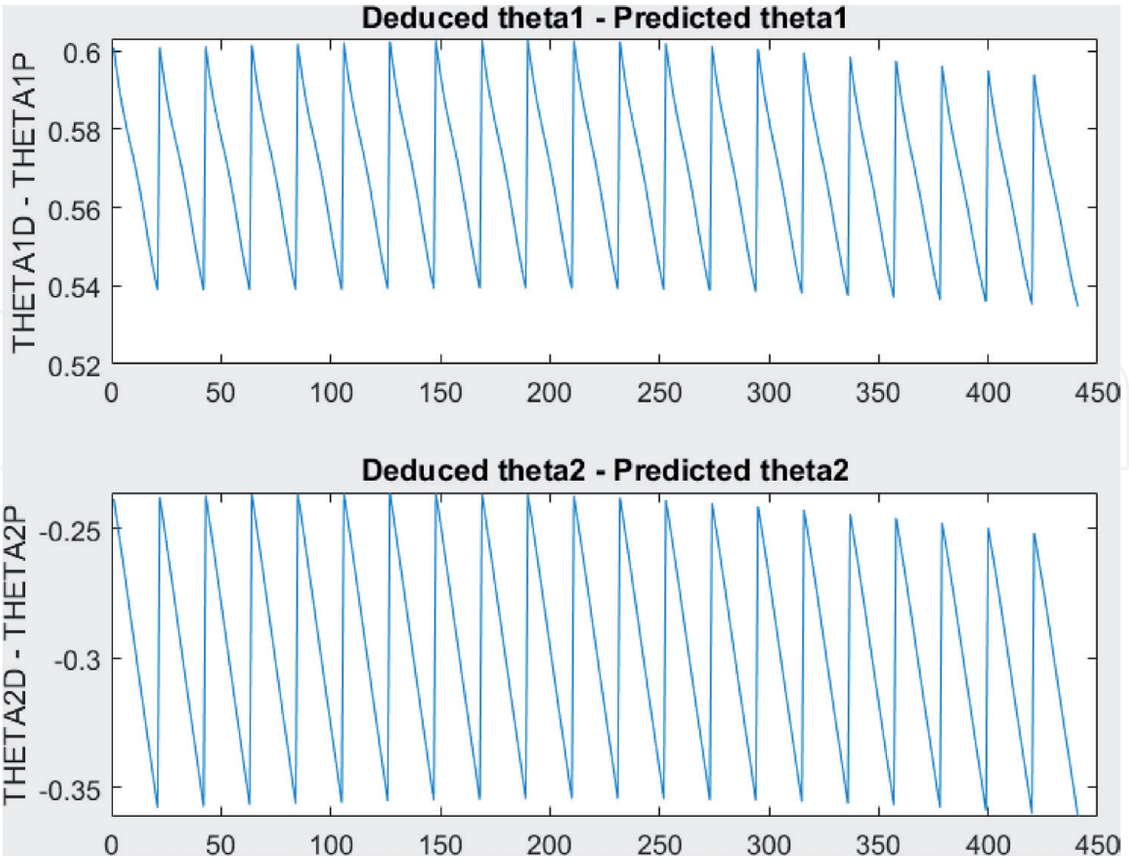


Figure 7.
Deduced and predicted angles of joint.

when needed [18, 19]. Hence, the design of jigs for assembly operation takes into account the cost, time, safety, flexibility, degree of interchangeability, efficiency, surface finish among other factors. This will permit machining of complex geometries to the desired surface finish. For instance, during welding operations, the expansion of work piece and locator due to heat call for more clearance between the locator and the work piece to facilitate easy unloading. Following the supply of the part lists, which are the standardised elements to be held by a jig during the assembly operation, the sorting of the parts into their respective families, is made based on their differences and similarities. Different part families requires different jig orientation hence the need to sort the parts out into their respective families as parts of the same family can be held with the same jig. For instance, the upper and lower brackets of the rail car consists of hundreds of parts that need to be sorted out into part families, followed by the development of specialised jigs for each family before they are welded on to the underframe through arc welding.

The cost analysis of the robotic welding considers the following; the total welding time, weld size, arc on time, deposition rate of the weld and the labour cost.

The total welding time is the sum of the total arc time and the non-arc time as expressed by Eq. 1. While the arc time is the time spent by the robot during the welding operation, the non-arc time is the time spent on other activities such as set up (loading and unloading), inspection, changing wire, shielding gas or contact tips etc.

$$T_t = A_t + N_t \tag{1}$$

T_t is the total welding time (s); A_t is the total arc time (s) and N_t is the non-arc time.

The operating factor (*OF*) is expressed by Eq. (2).

$$OF = \frac{A_t}{T_t} \tag{2}$$

2.3 Additive manufacturing in mass production

The additive manufacturing has opened up new design possibilities that would help meet the challenges relating to manufacturing processes. Manufacturing processes have shown a rapid development in this present day of industrialisation. As such, keeping up with the demands of sustainability, ever changing market dynamics, and environmental pressure, existing processes and practices are being improved and new technologies are being introduced resulting in an enormously expansion to the size and scale of industrial production [20]. Owing to the movement of mass production to developing countries, a rapid attention is paid to low volume innovative production of customised and sustainable products with high added value being observed with evolving manufacturing technologies to stabilise the economies of other domicile producing countries. In the same manner, competing with the ever-changing supply dynamics as a result of globalisation, manufacturing industries sought after new fabrication techniques to prepare themselves with the necessary tools for increased flexibility and economic low volume production. Additive Manufacturing is considered as one such technique of preparing for mass production due to its flexibility in manufacturing.

Additive manufacturing (AM) is defined as "the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining" according to American Society of Testing and Materials [21]. A lot have already been achieved on the way to the widespread application of AM technology. This is not limited to new design freedom, elimination of tools and fixtures, economic low volume production. However, the present and future development in the additive manufacturing industry should be adopted by industries as this new and potentially disruptive technology can be explored to produce high value products and generate new business opportunities [22].

The ability to fabricate several physical models directly from digital data is a key factor to ensuring product development cycle, hence, assisting in the intelligent manufacturing of products. This is in line with Industry 4.0 depicts smart production. Given that AM is an embedded technique in a digitally connected factory, it involves a lot of information and data processing and transmission between the manufacturing parties involved. Much of the information acquired and transmitted will be of great value during production, thereby, enhancing mass production [23].

In traditional means of production such as injection moulding, "tooling costs" are significant, accounting for as much as 93.5% of traditional manufacturing costs, while in AM the only outlay involved is in updating the design files [24]. Instead of economies of scale, AM can create "economies of scope". As there are, fewer costs associated with switching between making different things, adopting the technology makes it easier for companies to bring a range of products to market.

Adopting and modifying the architecture of the framework proposed by Mellor et al. [22] by focusing on technological variables. The technology factors in the production creation process through AM have been categorised into front-end factors comprising data-preparation and applied software, into machine related factors such as raw material supply, maintenance issues, production capacity and surface quality, and into back-end factors that comprise post-processing steps. The technological factors are as depicted in **Figure 8**.

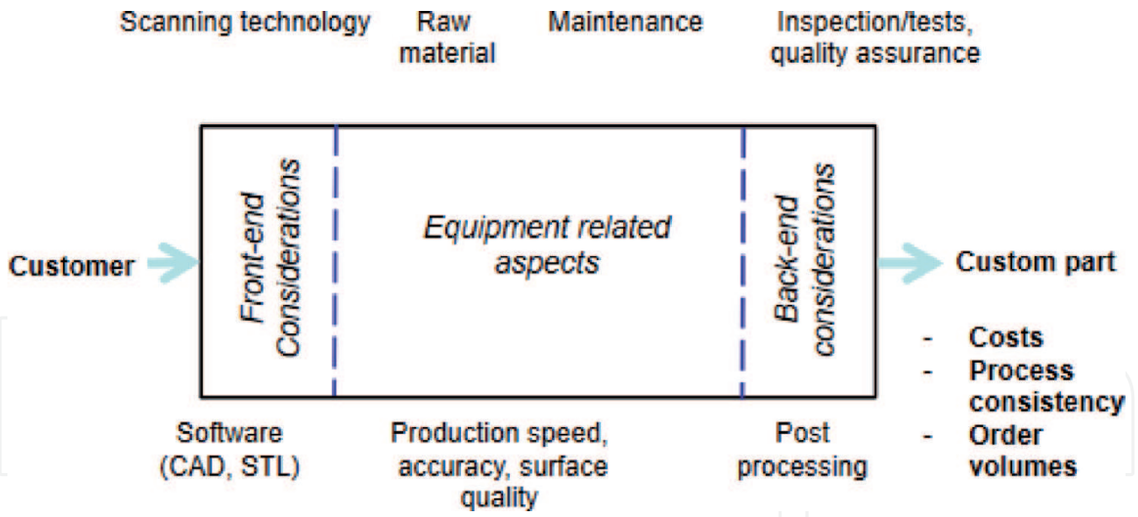


Figure 8.
Technology factors in the AM production creation process [22].

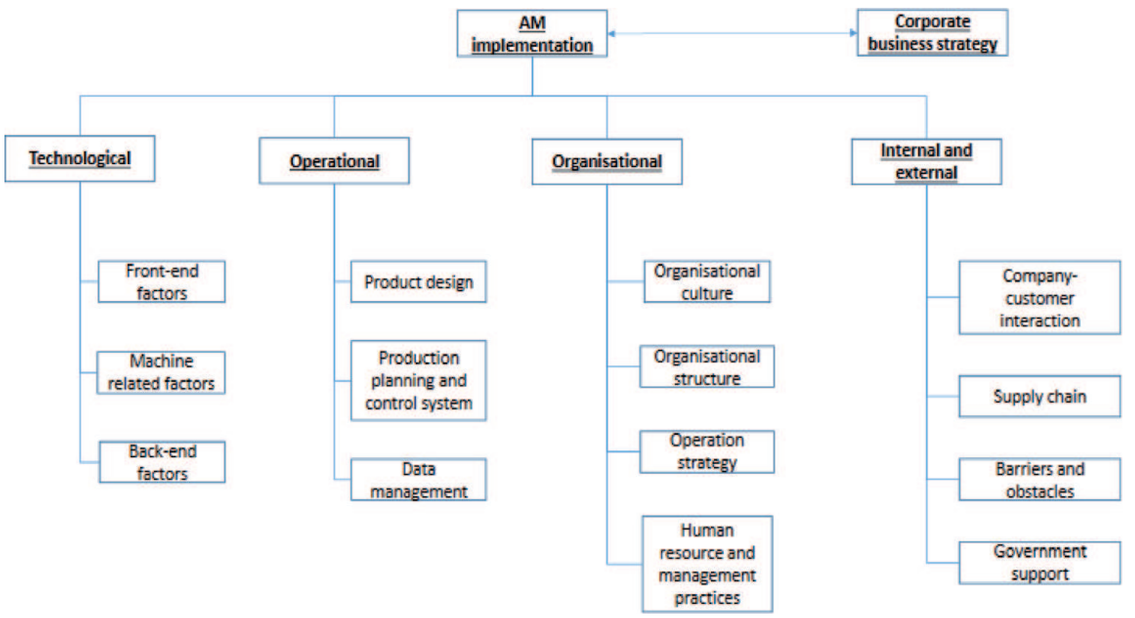


Figure 9.
Framework for influencing additive manufacturing implementation for mass production [22, 25].

Products suitable for AM production are desired to have one or more of the following characteristics: high degree of customisation, increased design optimised functionality and low volume production. The factors influencing AM implementation for mass production are categorised into technological, operational, organisational and internal/external factors according to Saberi et al. [25]. These are further enlisted in **Figure 9**.

2.3.1 Factors influencing additive manufacturing implementation for mass production

The factors influencing additive manufacturing implementation for mass production are as follow;

a. **Technological factors:** Additive manufacturing involves the elimination of tooling and fixturing, design modification for flexibility and function, lower material wastage and inventory etc. Hence, technological considerations are

divided into front-end factors, machine related factors, back end factors and overall process challenges.

b. **Operational factors:** Production planning and control systems are crucial in all evaluated cases for controlling for the quality of the process output. The unique characteristics of the additive manufacturing processes require new design tools and practices to be developed. There is not an absolute geometric freedom and based on the specific process, different considerations have to be taken into account when designing products.

c. **Organisational factors:** The operation strategy for AM systems vendor is characterised by offering comprehensive customer support and by deriving revenues from powder supply and maintenance service. Organisational structure of a company, often defined by its size, is the key factor to successful implementation of new manufacturing technology and therefore it could be essential for an organisation to first re-design organisational structures and processes before adopting a new manufacturing technology [26].

d. **Internal and external factors:** The level of success in the implementation of a complex technology innovation is often related to the level of user-supplier interaction. Machine manufacturers and other additive manufacturing technology companies can play a role in effective implementation of the technology by advising on operational and organisational changes to the user geared towards mass production.

2.3.2 Simplification of production processes, cost reduction prospects for mass enterprises

AM technology also enables some manufacturers to alter their production processes, simplifying supply chains by reducing the number of assembly steps that a product must undergo to reach its final form. AM does this by giving designers the ability to redesign parts to take advantage of part and sub-assembly consolidation. Parts and sub-assemblies machined as separate pieces can be manufactured as single objects using AM. This can have major impacts on the supply chain, including reductions in labour inputs, the required tooling and machining centres, and work-in-process inventory [27].

3. Conclusions

In this work, the deployment of recent technological advances relating to the fourth industrial revolution particularly the use of robotic and additive manufacturing solutions for mass production in the rail industry was discussed. A dual arm, 12-axis welding robot with advance sensors, camera and algorithm as well as intelligent control system was designed in the Solidworks 2017 environment and simulated using the adaptive neuro-fuzzy interference system (ANFIS) in order to evaluate the performance of the robot and determine the kinematic motion of the robotic arm. The simulation results showed the smooth motion of the robot and its suitability to carry out the welding operations for mass production of components during rail car manufacturing. In addition, the prospects of additive manufacturing for mass production in the rail manufacturing industry can be harnessed due to its ability to fabricate several physical models directly from digital data through additive manufacturing. This is a key factor in ensuring mass production and rapid product development cycle.

4. Recommendations

Furthermore, the deployment of virtual and augmented reality (VAR), with machine vision and light-based communication technologies (LiFi); artificial intelligence (AI) and digital solutions in rail car manufacturing as well as monitoring systems with low-cost sensor networks and smart algorithms are will boost mass production, cost effectiveness, process improvement, reliability and safety in the railway industry. It will also make the supply chain faster and flexible with attendant increase in productivity and efficiency due to access to real time data, digital business models and virtual simulation tools. This will also bring about significant improvement in the developmental stages of the rolling stock, which encompasses design, fabrication and optimization.

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