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Design Fabrication and Performance Evaluation of Electrically Operated Wheel Barrow

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ABSTRACT
The objective of the study was to design, fabricate and evaluate the performance of an electrically operated Wheelbarrow. The 9-step Design Model by Science Buddies was adopted with modification. The researchers also applied the Department of Training and Workforce Development of Australia method of fabrication with modification. The fabricated system was tested for capacity and lifting force, motorization ability/electrical self-moving capability, the battery run time among others as part of performance evaluation. Findings revealed that the wheelbarrow dimensions conform to the standard requirement. The minimum lifting force of the wheelbarrow for a weight of 1470N is 1241N. The test for motorization ability/electrical self-moving capability showed that the torque power of the wheelbarrow motor could not move heavy loads automatically without manual assistance. The batteries used to power the electric wheelbarrow could only last for approximately 1 hour 5 minutes which is about 77% of the theoretical run time amongst others. It was concluded that further iterations and probably redesigns where necessary is required to improve on the project.

KEYWORDS: Wheelbarrow, Design, Fabrication and Performance Evaluation

I. INTRODUCTION

The need for carrying loads from one destination to another most especially in the Construction Industry has been a serious challenge to mankind over the years. It was an effort to address this challenge that lead to the invention of the Wheelbarrow. Therefore, the Wheelbarrow is one of the equipment invented to move loads from one place to another, most especially in the Construction Industry. According to Wikipedia (2021)**,** Wheelbarrows are used for a variety of things, such as moving rock, mulch or compost to the garden, moving trees or large shrubs from one spot to another, hauling bricks, disposing of garden debris, or even for mixing concrete or fertilizers. According to Nwabuzor (2013), a wheelbarrow is a small hand propelled vehicle usually with just one wheel, designed to be pushed and guided by a single person using two handles to the rear or by a sail to push the ancient wheelbarrow by wind. The manually operated Wheelbarrow consists of three parts namely the tray, bowl, metal support, wheel and handles (Engineering and construction 2021)

There are different types of wheelbarrow but the Traditional wheelbarrow with two handles that are stocked straight out towards the user is the most common in Nigeria (Stratosphere, 2021). The traditional handle makes it easy to dump, flip, tilt, and turn the wheelbarrow. But the major disadvantage is that users have to be stronger to be able to easily use this type of wheelbarrow. The usage of the manually operated Wheelbarrow

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usually leads to fatigue while transporting heavy loads over a considerable distance. For instance, Nawik, Deros, Rahman, Sukadarin, Norani, Tamrin & Bakar (2015) reported that intensive manual handling and labor activities involved have been found to be associated with high prevalence of Musculoskeletal Disorders (MSDs) among palm oil plantation workers. Users of Manually operated Wheelbarrow are usually weak with fatigue after a long push to transport loads from one destination to another. Hence the need for elimination of the push through electrically operated sub-system. The electrically operated wheelbarrow uses electrically operated Motor to replace the manually push required. It has the advantage to utilize electric motor in order to do tasks efficiently. With the incorporation of the motor and source of electricity as parts of the manual Wheel Barrow, it will be easier and faster to accomplish work with no manual push. The user is only required to control the movement of the wheelbarrow using the handle. It is easy to operate as the handle could be used to steer it to anywhere. At the movement the electrically operated wheel Barrow cost much in the Nigerian market because of the high Dollar exchange rate. Against this challenge of the push required for the operation of the manual wheelbarrow, the advantages of the electrically operated type and its high cost in the Nigerian market, the need for design, fabrication and evaluation of an electrically operated Wheelbarrow locally in order to help Users reduce the Fatigue, risks and injuries associated with manual type and assist Nigeria in achieving the objective of the Executive Order 5 cannot be overemphasized.

Statement of the Problem

The manually operated Wheel Barrow was designed to be pushed by user to move goods from one location to another. Intensive manual handling and labor activities involved in the Manual Wheelbarrow have been found to be associated with high prevalence of tiredness and musculoskeletal disorders (MSDs) among its users (Godilano, Casas & Vargas, 2018). Against this backdrop there is a need for electrically operated Wheel Barrow which is safer in technology and could help its users reduce the risks and injuries. The review of related literature on electrically operated Wheelbarrow has revealed that there are varieties of designs but mostly designed and fabricated outside Nigeria and imported which have made their prices very high due to rising Naira to Dollar Exchange. Further, their continued importation and use are against the Presidential Executive Order 5 which is a key to achieving self-reliance, self-sufficiency through Local Content development in Science Technology and Innovation (STI). The Problem of the study therefore, is the need for an electrically operated wheel Barrow, cheaper in cost and functions exactly like the imported ones.

Justification

Although successes have been recorded so far in the design and fabrication of electrically operated Wheelbarrow, however in some cases the emphasis has always been on machines that rely on fossil fuel as a source of power which makes their application and utilization not eco-friendly.

Objectives of the Study

The major objective of the study is to design construct and evaluate the performance of electrically operated wheelbarrow which is cheaper in cost and functions like the imported ones. The Specific Objectives of the Project are to:

1. Produce the Design specifications for electrically operated wheel barrow
2. Fabricate the design of the electrically operated wheel barrow
3. Evaluate the performance of the fabricated electrically operated wheel barrow

Research Questions

The research was guided by the following research questions;

1. What is the Design specification for electrically operated wheel barrow?
2. How can the various components of the electrically operated wheel barrow be constructed/fabricated and assembled?
3. What will be the performance of the electrically operated wheel barrow in terms of endurance, motorization ability?

Scope of the Study

The Scope of this Research is to design, Construct and evaluate the Performance of a Single Wheel Barrow suitable for domestic, industrial, agricultural and building-site conditions in Nigeria.

II. LITERATURE REVIEW

Several studies have been carried out on the Design and Fabrication of electrically operated Wheel Barrow but most of such studies were carried out outside Nigeria and therefore, the products' costs are on the high side if imported into Nigeria because of weak value of Naira. In addition, their importation will not help Nigeria to archive its local content Development objectives. Wagner cited in Kailani, Bukar & Usman (2023) carried out a study on design and fabrication of powered wheel barrow. The objective of the study was to introduce automation sub-system that will help the user of the manual wheel barrow operate it. The Powered Wheelbarrow aims to add automation to the wheelbarrow in order to help people conserve their energy while using it. Extensive research found various existing products such as the Jackson wheelbarrow, the Gorilla Cart and the Lifetime brand wheelbarrows, but all of these products still lacked the automated performance proposed by the Powered Wheelbarrow. One existing product, the Power Buggy, did have a motor on it, but at a price of nearly $10,000, it is marketed more for businesses and not the everyday homeowner/handyman. Customer input was collected and analyzed which led to the most important characteristics being durability, ease of unloading and maneuverability. Further, it was also determined that in order to meet these customer requirements, the power of the motor, the overall weight and the material selected would be key characteristics to focus on. The design phase started by weighing different options in order to find the best motor to drive the wheelbarrow and the best way to dump the load without human power. It was ultimately decided that the motor from an IZIP i500 electric scooter would be best for the drive motor and a Black Bull electric car jack would be the best alternative to dump the load. Next, a support was designed to hold the jack and two other frames were designed to allow the bucket to pivot above the tire and dump the load without lifting the frame; like a dump truck. Once the design work was completed and all of the necessary material was acquired, fabrication and assembly took place. Operations such as metal cutting with a band saw, grinding, TIG welding, and nut and bolt assembly all led to the successful creation of the final Powered Wheelbarrow assembly. All the pieces were then painted in Rustoleum paint in order to help protect everything from the elements. Through testing, the Powered Wheelbarrow proved to meet the goals set out. It successfully carried a 210lb load across flat ground, up a 30° incline and through a basement being remodeled. Additionally, the jack was able to achieve its maximum height with the 210lb load and it was simple to dump the load the rest of the way. The Powered Wheelbarrow maintains its ability to perform like all other wheelbarrows while also being able to lighten the burden on the operator. Multiple trips, uphill treks and tight turns are now easier to perform with the Powered Wheelbarrow. The energy saved by the Powered Wheelbarrow can now be put into the task at hand. The major drawback of the Design is that it cost so much in Nigeria and its importation is against the implementation of the Executive Order on Local Content Development.

Samphina Academy (2022) reported the design and construction of a standard wheelbarrow that can be used by labourers, farmers, gardeners and others to transport goods from one place to another. The purpose for producing the wheelbarrow was to reduce, alleviate and possibly alleviate the sufferings, time, money, wastage of manpower and more especially the need for technological breakthrough and self-reliance which has been a major concern of any nation. The procedure they used in carrying out the fabrication include: marking out, pattern development, cutting, drilling, boring and welding operations. High quality materials were used to construct the wheelbarrow that possesses the required standard.

Sumarsono, Heryana, Adhitya, Nazaruddin, Siregar (2021) undertook a study aimed at determining and analyzing the performance of an electric motor installed in a small city car, which was an internal combustion engine (ICE) car with manual transmission and front-wheel drive converted into an electric vehicle. A manual transmission vehicle was used, considering its type is the cheapest. This was to push aside the perception that electric cars are not accessible to the lower classes. Another technical matter was the focus on the power and torque performance of the electric motor and the transmission. A 7.5 KW three-phase induction motor was installed and assembled with 200 AH 76.8 VDC batteries. Electronic power steering (EPS) and the air conditioner (AC) were not operated, while power for the electrical accessories and power analyzer was obtained from a separate 12 VDC battery. Vehicle analysis focused on the power consumption, which was measured and acquired using a power analyzer. The vehicle was driven in real terms with three passengers. GPS was also used to determine the vehicle position and collect elevation data during testing. The derivatives of the GPS data were the speed, acceleration, and distance traveled by the vehicle. The initial hypothesis was that the car could cover a distance of 30 km with regular usage.

Zarma, Galadima& Aminu (2022) reviewed on Motors for Electric Vehicles. According to them the need for clean energy and

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the need to cut carbon dioxide emission from internal combustion engines led them into the possibility of exploring new drive systems. They reviewed different electric motors with respect to their design simplicity, cost, ruggedness and efficiency. The researchers reviewed both alternating current (AC) & Direct Current (DC) electric motors. The AC motors comprise Synchronous motors (Permanent Magnet Synchronous Motor, the Stepper Motor, the Switched Reluctance Motor). While the DC motors are Asynchronous Motors (Induction Motors) which include: brushed DC motor; and the brushless DC motors. They discussed in detail the Working principles, operational requirements, excellent features and drawbacks of all motors available. The brushless DC motor was proven to be an efficient candidate for application in electric drive trains. This motor offers extraordinary power density, high efficiency and is cheaply available. The popularity of this motor as used as an electric drive train is also presented.

Hashernnia & Asaei (2008) Conducted a comparative Study of Using Different Electric Motors in the Electric Vehicles. In their work, different electric motors are studied and compared to see the benefits of each motor and the one that is more suitable to be used in the electric vehicle Electric Vehicles applications. There are five main electric motor types, DC, induction, permanent magnet synchronous, switched reluctance and brushless DC motors are studied. It is concluded that although the induction motors technology is more mature than others, for the Electric Vehicles applications the brushless DC and permanent magnet motors are more suitable than others. The use of these motors will result in less pollution, less fuel consumption and higher power to volume ratio. The reducing prices of the permanent magnet materials and the trend of increasing efficiency in the permanent magnet and brushless DC motors make them more and more attractive for the Electric Vehicles applications.

Research Design

The study adopted the research and development (R&D) design. Specifically, the Design Model by Science Buddies (2021) was adopted with modification. This involve defining the problem, Background check, specification of design requirements, brainstorming solution, developing solution, testing and redesign, and communicate results.

Area of the Study

The study was carried out at the respective workshops of the Departments of Electrical Technology Education and Department of Mechanical Production Technology Education, College of Technical and Vocational Education (CTVE), Kaduna Polytechnic, Kaduna, Nigeria.

Material Selection

The following factors were considered in the selection of the materials for construction/fabrication:

1. Local Content development policy: Most of the materials used for the project were locally sourced.
2. Availability of materials: - The materials used were selected based on their availability in the market.
3. Mechanical properties which include strength, toughness, Stiffness, Fatigue hardness and wear resistance.
4. Mechanical properties which include strength, toughness, Stiffness, Fatigue hardness and wear resistance.
5. Cost of Materials: - Materials used are available at a cheaper cost all over the country.
6. Strength of Materials: - In order to avoid operational failure the strength of the materials used were ascertained.
7. Electrical Power Consumption: Electrical components used are direct current (DC) lower power consumption types.

Brainstorm Solutions: The researchers studied existing electrically operated types and through the method of Sketching and doodling the following sub-units of the system was generated and produced in Block Diagram as follows:

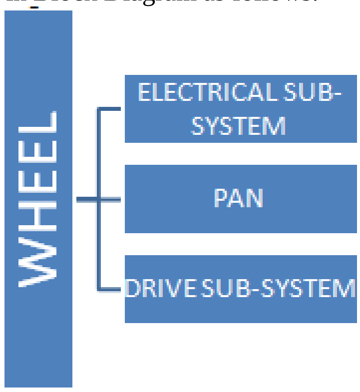

Fig. 1 The Block Diagram of the Electrically Operated Wheel Barrow

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Design Requirements: The Dimensions of the Single Wheel Barrow are as follows:

- Width of pan Max 760MM
- Height of the Pan lip Max 550MM
- Height of end of handles min 550 Max 700MM
- Distance between ends of handles Min 480 MM, Max 560MM
- Distance from wheel center to pan/tray Max. 225MM
- Distance from wheel center to ends of handles min 1220MM
- Pan Capacity: Min 40MM and Max 60 mm
- Disc Wheel Dimensions: Minimum outside diameter 250 MM and Minimum rim width at periphery 45MM
- Wheel: Pneumatic Tyre
- Carry up to –150Kg of Load without failing
- Cost less than the Foreign types
- Made up of local materials
- Resistance to corrosion
- Natural rubber handle.
- Electrically operated
- **Colour:** Green

Components of the Electrically operated Wheel barrow

The Electrically operated Wheel barrow comprised of the mechanical and electrical components. **Mechanical components**: The mechanical comprised the following**:** (i) The wheel, axle and shaft (ii) the handles (iv) Tyre (v) Tyre gear wheel, (vi) motor gear wheel (vii) casing for battery charger (viii) steel rod support for battery (ix) leg (x) the pan.


Fig.2 Pan/handle


Fig.3 Wheel, Axle & tyre


Fig.4 Leg/pan seat


Fig.5 Motor gearwheel


,Fig.6 Wheel gear


Fig.7 Battery/Charger casing


Fig.8 Nose guard


Fig. 9 Motor gear

Fabrication Process

Department of Training and Workforce Development of Australia (2016) method of fabrication was adopted with modification.

The Pan: Due to non-availability of a metal forming machine required to produce the pan, triangulation method of pattern development was used to fabricate the pan.

Handle: Round bar of 30mm diameter, 4mm thickness was used to fabricate the handle with the aid of round bar bending machine.

Gears: The motor gear (drive) and the wheel gear (driven) were fabricated in the foundry workshop through metal casting. Scraps were melted in the furnace above its critical point, then poured into the required mould and allowed to cool before they were removed and finally dressed with the aid of angle grinder.

Wheel and Tyre: The Wheel and Tyre were sourced locally from the market.

The seat/Stopper: Flat bars 50mm by 5mm thickness was used to fabricate the seat/stopper.

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The bending of seat/stopper was done with the aid of ball-pein hammer and anvil.

The seat for Electric motor: The seating for electric motor was produced with sheet metal plate of 4mm thickness.

The shaft: A round bar of 50mm diameter was reduced through lathe turning to 30mm and used as the shaft for the wheelbarrow. The housing for the shaft was welded to the handle via electric arc welding and finally dressed with an angle grinder.

Finishing: Emery cloth was used to remove the rough particles, cleaned and wire brushed. The wheelbarrow was painted green with the aid of a compressor paint sprayer.

The Electrical Components: The electrical components comprised (i) DC shunt (ii) batteries (iii) Headlamp (iv) buzzer or horn accessory (v) flexible cables (vi) switches (vii) clips



Fig.10. DC Shunt Motor Fig.11. Batteries Fig. 12. LED headlamp Fig.13. Buzzer



Fig.14. Headlamp switch Fig.15. Motor start switch Fig.16. Horn switch

The electrical components were sourced locally from the market.

Shunt wound motor

This is the most common types of DC Motor. Here the field winding is connected in parallel with the armature as shown in the figure below:

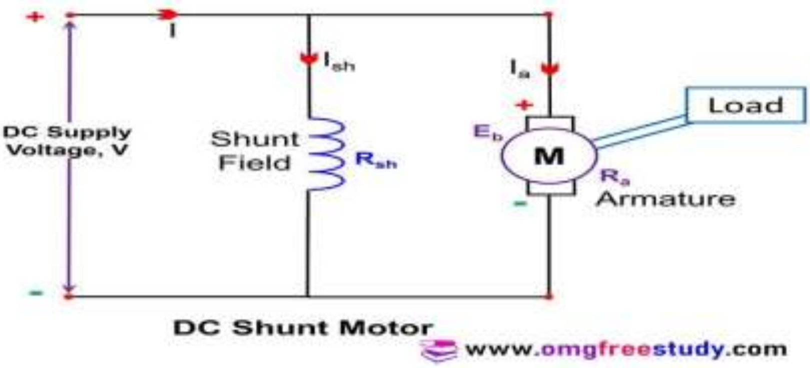

Fig.17 DC shunt motor on load

Calculating Mechanical Power Requirements of the motor for the wheelbarrow

Physically, power is defined as the rate of doing work. For linear motion, power is the product of force multiplied by the distance per unit

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time. In the case of rotational motion, the analogous calculation for power is the product of torque multiplied by the rotational distance per unit time. P_{rot} = M x ω. Where: P_{rot} = rotational mechanical power; M = torque; ω = angular velocity (Faulhaber Group, 2023). The most commonly used unit for angular velocity is rev/min (RPM). In calculating rotational power, the velocity was concerted to units of rad/sec. This was accomplished by simply multiplying the velocity in RPM by the constant (2 x π) /60: $\omega_{rad/sec} = \omega_{rpm}$ **x** [2π/60]

Current, voltage and power equations for the shunt motor

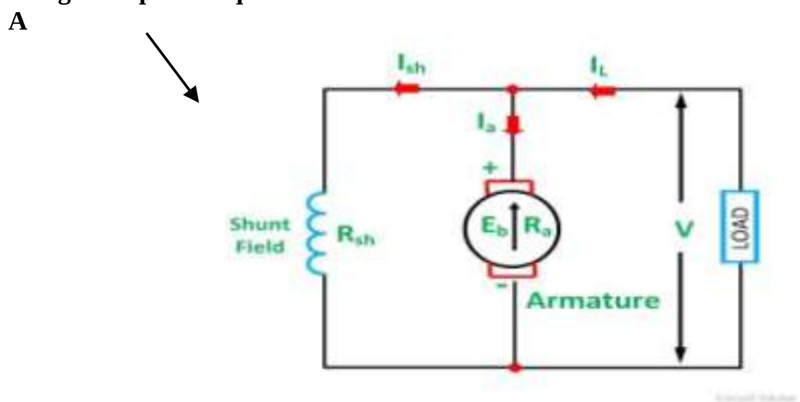

Fig.18 DC shunt motor (Source: Circuit Globe, 2023)

The current, voltage and power equations for a shunt motor are shown as follows.
By applying KCL at junction A in the above figure.
The sum of the incoming currents at A = Sum of the outgoing currents at A.
$\mathbf{I = I_a + I_{sh}}$ **--------------(1)**
Where, I is the input line current; I_a is the armature current; & I_{sh} is the shunt field current
Equation (1) is the current equation.
The voltage equations are written by using Kirchhoff's voltage law (KVL) for the field winding circuit.
$\mathbf{V = I_{sh} R_{sh}}$ **--------------- (2)**
For armature winding circuit the equation will be given as:
$\mathbf{V = E + I_aR_a}$ **------------------ (3)**
The power equation is given as:
Power input = mechanical power developed + losses in the armature + loss in the field.
$\mathbf{VI = P_m + I_a^2R_a + I_{sh}^2R_{sh}}$ **--------------------(4)**
$\mathbf{VI = P_m + I_a^2R_a + VI_{sh}}$
$\mathbf{P_m = VI - VI_{sh} - I_a^2R_a = (V - I_{sh}) - I_a^2R_a}$
$\mathbf{P_m = VI_a - I_a^2R_a = (V - I_aR_a)\, I_a}$
$\mathbf{P_m = EI_a}$ **--(5)**
Multiplying equation (3) by Ia we get the following equations.
$\mathbf{VI_a = EI_a - I_a^2R_a}$ **-------------------(6)**
$\mathbf{VI_a = P_m + I_a^2R_a}$ **-------------------(7)**
Where, VI_a is the electrical power supplied to the armature of the motor.

Testing Methods

The failure mode and failure analysis method was used to test the electrically powered wheelbarrow. Failure mode and effects analysis is the process of reviewing as many components, assemblies, and subsystems as possible to identify potential failure modes in a system and their causes and effects (American Society for Quality, 2023). Therefore, the following tests were carried out:
Inspection: The researchers visually examine and then measure dimensions of the wheelbarrow for compliance with those requirements of the standard for which tests to assess compliance in terms of dimension the height, handle-to-handle gap, and grip diameter of the handle by applying the concepts of Anthropometry. Anthropometry is the science that defines the physical measure of a person's or object's size, form and functional capacity. The wheelbarrow dimensions were found to conform to the standard requirement.
Capacity test: Stand the wheelbarrow so that the rim of the pan is horizontal. Fill the pan with water to overflow. Measure, to the nearest half-litre, the volume of water in the pan. The outcome of the test was satisfactory.
Determination of lifting force: Load the pan of the wheelbarrow with 150 kg ± 1 kg of sand. Measure the total vertical force (applied equally to both handles at a point at least 25 mm from the ends of the handles) required to hold the wheelbarrow with the rim horizontal. The lifting force (F) was determined as follows. The distance

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from wheel center to pan/tray is 22.5CM while distance from wheel center to ends of handles min 122CM, The researchers first of all determined the weight the wheelbarrow exerted on the earth at 150Kg load mass (150 x 9.8 = 1470N), then took moments about the pivot of the machine:

Anticlockwise moment = Clockwise moment
F(22.5 + 122) = (1470 x 122)
F(144.5) = 179340
Lifting Force (F) = 179340/144.5 = 1241N.

Therefore, the minimum lifting force of the wheelbarrow for a weight of 1470N is 1241N.

Testing of the lighting and Horning systems: After connecting the batteries to the electrical system of the wheelbarrow. The testing for lighting and horning was conducted by operating the relevant switches and the results were satisfactory.

Determination of the motorization ability/electrical self-moving capability: The electrically operated wheel barrow was tested under no-load condition and was found to be operating normally at a moderate speed. However, after loading the motor and tested. It was discovered that the torque power of the wheelbarrow is not yet capable of moving heavy loads automatically without manual assistance; consequently, there is need for more iterations and probably redesigns in order to fully achieve the objective of the project.

Determination of the Battery Run Time while On Load

According to DNK Power (2023) Battery Discharging Time equals to the product of Battery Capacity and Battery Voltage divided by the Device Power (Watt).

$$\text{Battery Discharging Time} = \frac{\text{Battery Capacity x Battery Voltage}}{\text{Device Power (Watt)}}$$

Where the Battery Capacity=14Ah; Battery Voltage=12V and Motor Power=120W

$$\text{Battery Discharging Time} = \frac{14(\text{Ah}) \text{ X } 12(\text{V})}{120(\text{W})} =$$

1.4hour (1 hour 24 minutes)

In view the above, theoretically the battery could power the electric wheelbarrow for 1 hour 24 minutes. However, practically after subjecting the project to test, the battery could only power the electric wheelbarrow conveniently for approximately 1 hour 5 minutes only before it battery becomes weak. The practical run time of the load while on load is approximately 77% of the theoretical time calculated.

III. RESULTS

The result of the research is a functional electrically operated wheel barrow which has been tested, however, there is still need to improve the product for optimum functionality. See figure 18.

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Fig.18. Electrically operated wheel barrow

IV. DISCUSSION OF RESULTS

The wheelbarrow dimensions were found to conform to the standard requirement. This partly agrees with the specification of products like endurance green wheelbarrows (Austen Group, 2023). The minimum lifting force of the wheelbarrow for a weight of 1470N is 1241N. The lighting and horning system functioned well. The test for motorization ability/electrical self-moving capability showed that the torque power of the wheelbarrow motor could not move heavy loads automatically without manual assistance. The batteries used to power the electric wheelbarrow could last for approximately 1 hour 5 minutes (effective run time) which is about 77% of the theoretical run time (1 hour 24 minutes) when calculated using formula. This implies that this electrically operated wheelbarrow at this present nascent state could not yet compete with products like Deleks (2023) XE-500He electrified wheelbarrow that can conveniently carry a load 500kg. This shortcoming therefore calls for further improvement on this project.

V. CONCLUSION

The electrically operated wheel barrow was designed, developed and fabricated. However, the torque power of the wheelbarrow is not yet capable of moving heavy loads automatically, as such, there is need for more iterations and probably redesigns in order to fully achieve the objective of the project.

Recommendation

1. More research and probably a more suitable electrical design calculation should be done for the motorization of the machine.
2. An alternative means or method of transmitting the rotary motion of the motor to the wheel of the wheelbarrow should be research upon and implemented to fully achieve the full objective the project.

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