ISA Journal of Engineering and Technology (ISAJET)

Homepage: https://isapublisher.com/isajet/

Volume 3, Issue 1, Jan-Feb, 2026 ISSN: 3049-1843

Design and Fabrication of Electric Motorized Barrow

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Received: *20.01.2026* | ***Accepted:*** *02.02.2026* | ***Published:*** *06.02.2026*

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DOI: *10.5281/zenodo.18506473*

Abstract **Original Research Article**

An escalating interest in commercially available electric load-transportation vehicles targets not only a diminished carbon footprint but also seeks to empower developing communities. This paper details the research, design, and fabrication of a low-cost ride-on electric barrow capable of transporting a full hopper load and an operator across the rugged terrain encountered at the Ogun State Institute of Technology, Igbesa. The design was required to be low-cost but durable, fabricated using quality materials, reliable, and operator-friendly. Key features of the design included the use of a standard off-the-shelf wheelbarrow at the center of the modular design. While not only reducing costs and improving the marketability of the final product, this also enhanced the usability of the product since the hopper operated as a traditional wheelbarrow. The final vehicle resembled a trike and was constructed from a rectangular tube steel and aluminum chassis, which was driven by two pneumatic wheels, and powered by a 2kW brushless direct current motor (BLDC). The final vehicle seated a single occupant, who navigated the design using the original wheelbarrow handles, which pivot through the chassis. The handles further possessed an ergonomic design with respect to the vehicle throttle control for the driver who was seated on a chair above the drivetrain of the vehicle. The gross mass that the vehicle was capable of transporting was 350kg. Specifications for driver positioning, capabilities, and range of motion were implemented by the authors to ensure an ergonomic design. The final design featured a wheelbase of 1.33m, a total length of 1.74m, and a maximum width of 1.05m. The vehicle was designed for male and female operators up to a total mass of 90kg, and travelled at a rated speed of 10km/h.

Keywords: Electric, Motor, Construction, Transportation, Modular, Traditional, Barrow.

1.0 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 led to the invention of the Wheelbarrow. Therefore, the Wheelbarrow is one of the pieces of equipment invented to move loads from one place to another, most especially in the Construction Industry (Okonkwo et al., 2021). Traditional wheelbarrows typically consist of a tray, a single wheel, and two handles, allowing users to move loads by lifting and pushing. 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. There are different types of wheelbarrows, but the Traditional wheelbarrow with two handles that are stocked straight out towards the user is the most common in Nigeria (Smith et al., 2021; Wang et al., 2024).

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 (Harrison et al., Kailani et al., 2024), 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 wheelbarrow by the wind. The manually operated Wheelbarrow consists of three parts, namely the tray, bowl, metal support, wheels, and handles. The traditional handle makes it easy to dump, flip, tilt, and turn the wheelbarrow. The usage of the manually operated Wheelbarrow usually leads to fatigue while transporting heavy loads over a considerable distance. (Nawik, *et al*, 2015) reported that intensive manual handling and labour activities involved are associated with a high prevalence of Musculoskeletal Disorders (MSDs) among palm oil plantation workers.

Users of manually operated wheelbarrows are usually fatigued after a long push to transport loads from one destination to another. Hence, there is a need to eliminate the push-through electrically operated subsystem (Johnson & Green, 2023). The electrically operated wheelbarrow uses electrically operated motor to replace the manual 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 wheelbarrow, it will be easier and faster to accomplish work with no manual push (Martinez et al., 2020; Smith et al., 2021). 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 cannot be overemphasized. The traditional manually operated wheelbarrow, while widely used, poses significant physical challenges to its users. The need to manually push and balance the load leads to rapid fatigue and increases the risk of MSDs among its users (Godilano, *et al*, 2018; Brown & Taylor, 2020). This issue is particularly pronounced in labour-intensive industries where workers rely on wheelbarrows for transporting materials frequently and over considerable distances. Despite the availability of electrically operated wheelbarrows that can mitigate these problems, their high cost makes them inaccessible to many users, particularly in developing countries. Additionally, reliance on imported electric wheelbarrows conflicts with local content policies aimed at promoting self-reliance and reducing dependency on foreign products. Given these challenges, there is a compelling need to design and fabricate an affordable, efficient, and locally produced automated wheelbarrow. This paper aims to develop an automated wheelbarrow that reduces the physical burden on users, minimizes injury risk, and adheres to local content development policies by using locally sourced materials and technologies. By addressing these needs, the project will help improve worker safety and productivity while supporting local manufacturing industries.

2.0 Materials and Methodology

This study entails the design, fabrication, and performance evaluation of an electric motorized barrow for use on farmland and construction sites. The methodology encompassed the design, selection of materials, fabrication, and testing of its performance to handle real-world applications and specifically the load requirements on construction sites. Suitable materials were carefully selected for the load carriage and frame. Due to high tensile and compressive strength, mild steel ASTM 572 was selected, so as to support the loads and the working terrain.

1.0 Description of the Electric Motorized Wheelbarrow

The electrically motorized wheelbarrow has three wheels (tri-cycle) as presented in a schematic in Figure 1.0. The wheelbarrow operates using an electric motor to move the wheels. Electrical energy from the battery is supplied to the electric motor. The motor converts the energy supply to mechanical energy and sends the torque to the wheels via a chain drive. The smaller sprocket is coupled to the motor while the bigger one is attached to the shaft at the rear, and the arrangement serves as speed reduction for the wheelbarrow. The control panel that is located at the back under the bucket serves as an interface to control the speed, direction, signal, and any other functions. The handle and the seat are positioned such that the operator finds it comfortable to maneuver different terrains, apply the brake, and manually tip the load while seated.

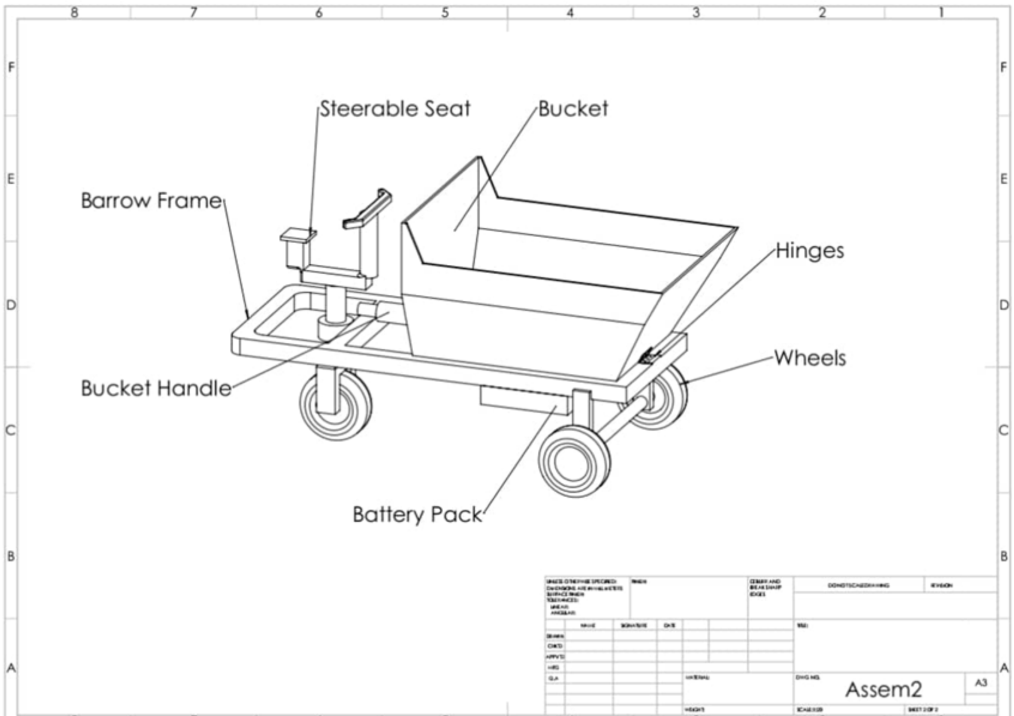


Figure 1.0a: Showing parts of the electric motorized wheelbarrow

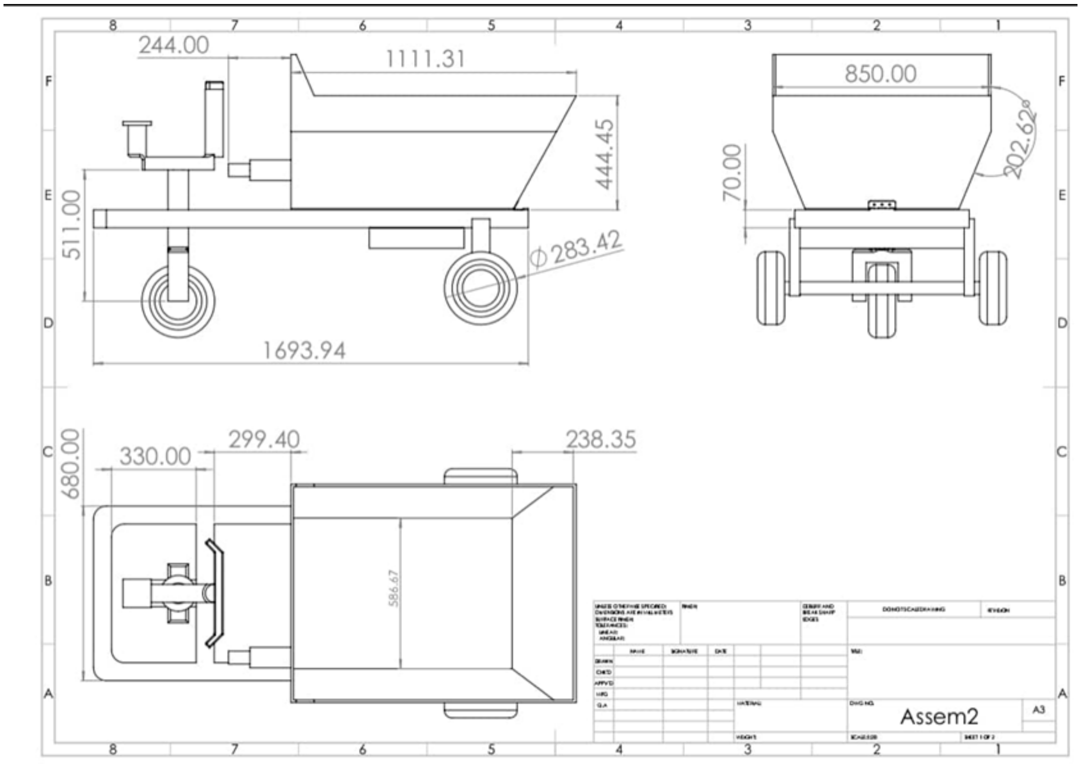


Figure 1.0b: Schematic of the electric motorized wheelbarrow

2.2 Functionality and User Requirements of the Machine

The design and construction of an electric motorized wheelbarrow were driven by three core elements: functionality, operational requirements, and user requirements. This essential consideration helps us focus on fabricating a wheelbarrow that can satisfy performance goals while maintaining user-friendliness, efficiency, and safety. Also, the key characteristics in the design consideration include ease of use, energy efficiency, quality of the output, and safety. Understanding these basic users' needs serves as a guide to creating a machine that can imitate a traditional wheelbarrow in a handy, mechanized fashion, making it accessible for many users.

2.3 Features of Electrical Motorized Wheelbarrow

The key features of the wheelbarrow include:

i. Tri-Wheel Design: The three-wheeled configuration ensures superior balance and stability, allowing the wheelbarrow to navigate uneven surfaces, slopes, and tight spaces with ease. This is particularly useful for environments that require constant maneuvering around obstacles.

ii. Electric Motor: Powered by an eco-friendly electric motor, the tri-cycle wheelbarrow minimizes the need for manual effort. This motor assists in carrying heavy loads without the need for strenuous physical labor, making it an ideal choice for reducing operator fatigue and increasing efficiency.

iii. Rechargeable Battery: The electric motor is powered by a rechargeable battery, offering an extended operational range with minimal environmental impact. The battery can be easily recharged between uses, ensuring the device is ready for continuous work.

iv. Bucket: The bucket is designed to hold a substantial amount of material, providing flexibility for transporting a wide range of items such as soil, construction debris, tools, and equipment. The bed is typically made from durable, weather-resistant materials to withstand demanding conditions.

v. Ergonomic Controls: The tri-cycle wheelbarrow is designed with user comfort in mind.

It features ergonomic handles, adjustable speed settings, and simple controls, making it easy to operate even on long workdays.

vi. Sustainability and Quiet Operation: The electric motor offers a quieter and more environmentally friendly alternative to gas-powered equipment, reducing emissions, noise pollution, and the need for constant fuel refills.

The tri-cycle electric motorized wheelbarrow combines the benefits of stability, power, and sustainability, making it an efficient and practical solution for any task that requires heavy lifting and material transport.

2.4 Design Requirements

The design of the electrically motorized wheelbarrow required is to determine the following:

i. The battery capacity that will start the system and store sufficient electrical energy that will keep the wheelbarrow running for at least 1 hour.
ii. The capacity of the electric motor that will convert the electrical energy to mechanical energy.
iii. The torque required to drive the shaft.
iv. The unit load that the bucket can carry at a time.

Predesign of the Motorized Wheelbarrow

The pre-design of the barrow was first done, such as the items to be bought, the height, and the width of the seat. The total length and the width of the machine were also considered.

Bucket breadth = min 480, max 580 mm
Bucket length = min 660, max 720 mm
Height of the bucket = 300 mm
Length of the handles = 860 mm
Height of the Seat = 500 mm
Length of the handle = 640 mm
Total length of the wheelbarrow = 1400 mm
Width of the barrow = 480 mm
Wheel diameter = 280 mm
Driver sprocket diameter = 55 mm
Driven sprocket diameter = 92 mm
Number of teeth of driver sprocket = 12
Number of teeth of driven sprocket = 22
Electric motor = 3 HP
Battery = 12 volts 38 AH (20 HR) 360 A
Method of tipping/dumping = Manual

Design Calculations

Power (P) = Torque (T) × Angular speed (ω) (1)

T = Force x radius

T = 36630 x 0.014 x 3600

Power generated by the battery

Two batteries of 12 volts each = 24 Vs

A 38 Ah battery is a battery with a capacity of 38 ampere-hours, which is a unit used to measure the amount of energy a battery can store. The higher the Ah rating, the longer the battery can power a device before needing to be recharged. Amp-hours, or Ah for short, are a unit of measure for a battery's energy capacity. This rating tells us how much current a battery can provide at a specific rate for a certain period. So, for example, if you have a fully-charged 5-Ah battery, it can provide five amps of current for one hour

The length of the chain

The schematic of the chain used is shown in Figure 3. The length of the chain that transmits power from the driver to the driven wheel (shaft) is given in equation (i). However, to calculate the length, certain parameters must be determined. Such parameters are (i) the pitch of the chain and (ii) the speed of the driven wheel. (Gupta (2009); Gupta (2009)).

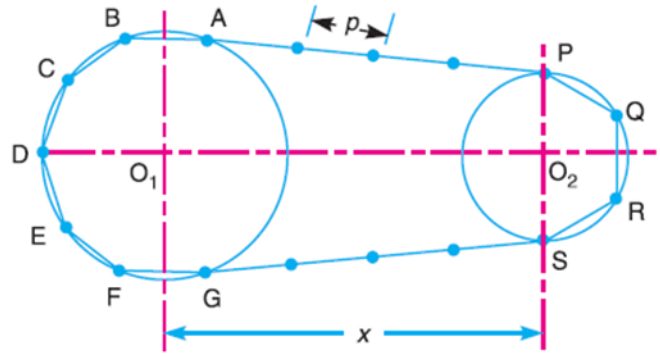


Figure 2.0: Showing the Chain of the Electric Motorized Barrow

$$L = \frac{P}{2}(T_1 + T_2) + 2x\ \frac{\left[\frac{P}{2}cosec\left(\frac{180°}{T_1}\right) - \frac{P}{2}cosec\left(\frac{180°}{T_2}\right)\right]^2}{x} \quad (2)$$

Where, T_1 = Teeth of the driver's sprocket = 12

T_2 = Teeth of the driven sprocket = 22

d_1 = Diameter of the driver's sprocket = 50 mm, $r_1 = 25$ mm

d_2 = Diameter of the driven sprocket = 90 mm, $r_2 = 45$ mm

x = Centre distance between the driver and driven shaft = 470 mm

Speed of the driver = N_1 = 3600 rpm

Speed of the driven = N_2 =?

The pitch of the chain = P =?

Speed of the driven

To determine the speed of the driven, equation (3) was used

$$\frac{N_2}{N_1} = \frac{T_1}{T_2} \quad (3)$$

$$N_2 = \frac{N_1 T_1}{T_2}$$

$$\boldsymbol{N_2} = \frac{3600 \times 12}{22} = \mathbf{1964\ rpm}$$

Pitch of the circle

$$r_1 = \frac{P}{2}\ cosec\left(\frac{180°}{T_1}\right) \quad (4)$$

$$r_2 = \frac{P}{2}\ cosec\left(\frac{180°}{T_2}\right) \quad (5)$$

Any of the equation (4) or (ii5) can be used to calculate the pitch (P), therefore, equation (i) is used

$$r_1 = \frac{P}{2}\ cosec\left(\frac{180°}{T_1}\right)$$

$$25 = \frac{P}{2}\ cosec\left(\frac{180°}{12}\right)$$

P = $\frac{50}{3.823}$ = 13

The pitch of the chain is 13

Length of the chain

Length of chain, L is given as

L = $\frac{P}{2}(T_1 + T_2) + 2x \frac{\left[\frac{P}{2} cosec\left(\frac{180°}{T_1}\right) - \frac{P}{2} cosec\left(\frac{180°}{T_2}\right)\right]^2}{x}$ (2)

L = $\frac{13}{2}(12 + 22) + 2(470) \frac{\left[\frac{13}{2} cosec\left(\frac{180°}{12}\right) - \frac{13}{2} cosec\left(\frac{180°}{22}\right)\right]^2}{x}$

L = 221+ 940 + 0.919 = 1161.919 mm ≈ **1.2 m**

The required length of the chain to transmit power and motion to the driven shaft is 1.2 m.

3 Horse Power = 3 × 746 = 2238 W

The torque required to drive the wheelbarrow

P = T ω (6)

T = $\frac{P}{\omega}$

$\omega = \frac{2\pi N}{60}$ (7)

Where T = torque of the motor (Newton-metre)

P = power of the motor (watt) = 2238 W

$\omega =$ angular speed (radian/second)

$\omega = \frac{2\pi \times 3600}{60}$ = 377 rad/s

T = $\frac{P}{\omega}$

T = $\frac{2238}{377}$ = 5.94 Nm

The torque generated is 5.94 Nm

The Mechanical power required to drive the wheel

$P_M = \frac{2\pi\omega}{60} \times T$ (8)

Where, $P_M =$ Mechanical Power

Force applied at the driven

T = Fr (9)

The radius of the driven = 45 mm

F = $\frac{5.94}{0.045} = 132$ N

Power required from a battery P

P = VI

For 2 batteries, V = 24 v

I = 360 A

P = 360 × 24 = 8640 W

Shaft analysis

Figure 3.0: Showing the Shaft

L_S = 480 mm = 0.48 m
D_S = 30 mm = 0.03 m
$\rho_S = 7850Kgm^{-3}$
$\tau_S = 360MPa$
$G_s = 78GPa$
$F_M = 115N$
$S_F = 1.5$

i) Mass of Shaft

$\rho_S = \frac{M_S}{V_s}$

$M_s = \rho V_s$

ii) Area of Shaft

$$A_s = \frac{{D_S}^2}{4}$$

$$A_s = \frac{\pi(0.03)^2}{4}$$

$A_s = 7.0695\times\ 10^{-4}$ m^2

iii) Volume of Shaft

$V_s = A_s \times L_S$
V_s = 7.0695 × 10^{-4} × 0.48
$V_s = 3.39336 \times\ 10^{-4}\ m^3$
$M_s = \rho_S\, V_s$

$M_s = 7850 \times$ 7.0695× 10^{-4}

$M_s = 2.6638$ kg

iv) Weight or force of the shaft

$F_s = M_s g$

F_s = 2.6638 × 9.81

F_s = 26.132 N

Bearing Analysis

Figure 4.0: Showing the Pillow Bearing

$L_B = 45mm = 0.045m$

$D_B = 30mm = 0.03m$

$\rho_b = 7850Kgm^{-3}$

i) Bearing Area

$A_b = \frac{{D_b}^2}{4}$

$$A_b = \frac{\pi(0.03)^2}{4}$$

$A_b = 0.0.00071m^2$

ii) Bearing Volume

$V_B = A_B \times L_B V_B$

$= 0.00071 \times 0.045$

$V_B = 0.000032m^3$

iii) Mass of Bearing

$\boldsymbol{\rho_B} = \frac{M_B}{V_B}$

$M_B = \rho_B V_B$

$M_B = 7850 \times 0.000032$

$M_s = 0.25Kg$

iv) Weight or Force of the Bearing

$\boldsymbol{F_B} = M_B g$

$F_B = 0.25 \times 9.81$

$F_B = 2.5N$

The Volume of the Bucket

The bucket used for this project work is irregular in shape and is calculated as follows

Volume (V) = Length (L) x Breadth (B) x Height (H)

Length = $\frac{72 + 66}{2} = 69\ cm$ = 0.69 m

Breadth = $\frac{58 + 48}{2} = 53\ cm$ = 0.53 m

Height = 30 cm = 0.3 m

V = $0.69\ \times 0.53\ \times 0.3 = 0.10971\ m^3 \approx \mathbf{0.1097\ m^3}$

i) Mass of Bucket

$\rho_B = \frac{M_B}{V_B}$

$M_B = \rho_B V_B$

$M_B = 7850 \times 0.1097$

$M_B = 861{,}15\ Kg$

Convert the volume to kilogram

0.1097 × 333 = 365301 Kg

Total weight = weight of wheelbarrow + carrying weight

3.0 Result and Discussion

The Electric motorized barrow is present in Figure 5.0. The front, side, and back views are visible in Figure 5.0. (a – c).

Figure 5.0a: Front View

Figure 5.0b: Back View

Figure 5.0b: Side View

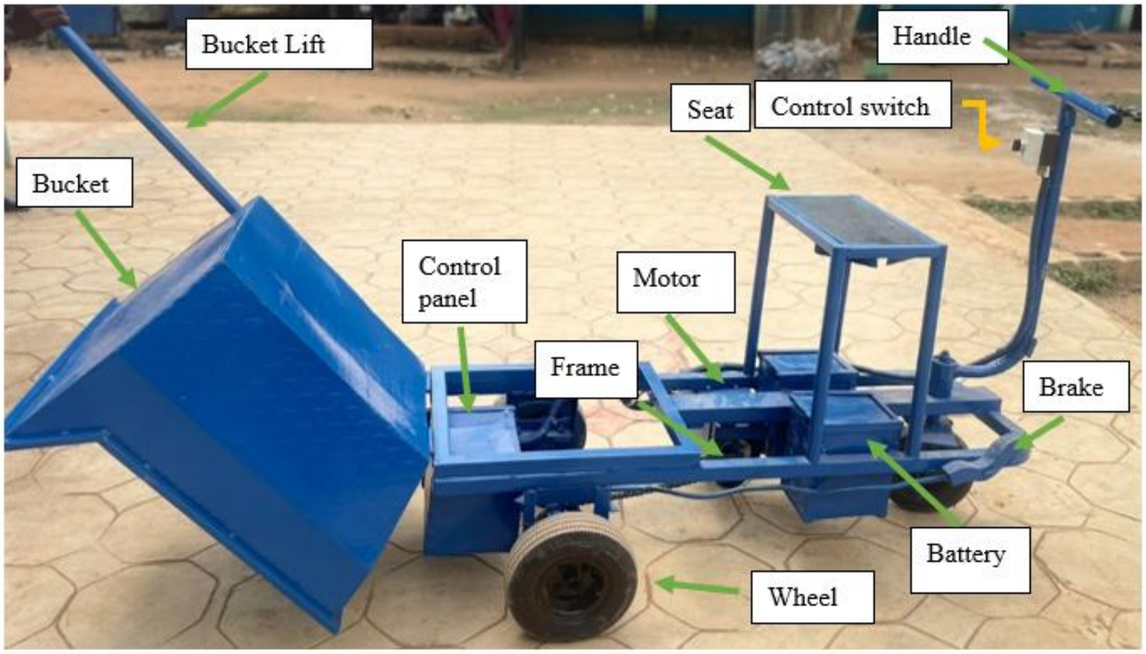


Figure 5.0c: Showing the side view of the electric motorized barrow with components

3.1 Performance Evaluation of Electric Motorized Barrow

3.2 Fabrication Outcome

The design, fabrication, and assembly of the electric motorized barrow were completed using locally sourced materials. The complete prototype shown in Figure 5.0 (a-c), which comprises a mild steel chassis, tri-wheel arrangement, electric motor drive system, rechargeable battery, chain transmission, control panel, and manually operated tipping bucket.

The final configuration maintained dimensional accuracy in conformity with design specifications, confirming structural balance, comfort of the operator, and efficiency. The tri-cycle arrangement promotes stability during operation, specifically during heavy loading over uneven terrain. During fabrication and post-assembly inspection.

3.3 Performance Evaluation

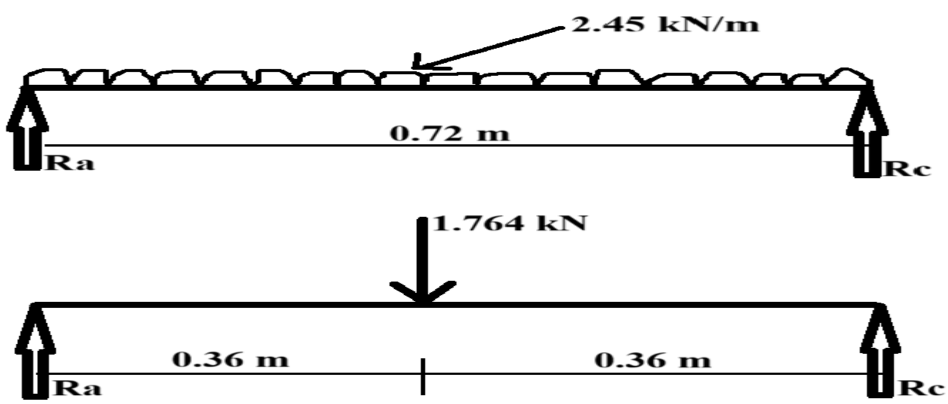
The performance of this electric motorized barrow was assessed under the load and no-load conditions on uneven terrain. The product was designed to carry a maximum load of 250kg, outside the self-weight of the barrow and the operator. During the full loading conditions, the product achieved about seventy-five percent of its no-load speed, which is an indication of an acceptable torque transmission and efficiency. Sufficient tractive force was provided by the electric motor to overcome rolling resistance and terrain-induced load differences without stalling. The mild steel (ASTM 572) frame, with a tensile strength of nearly 420MPa, demonstrated no observable plastic deformation or structural defects during testing. This ascertains the suitability of the selected materials for the envisioned load and operating conditions.

3.4 Structural Analysis Results

The structural integrity of the frame was evaluated via shear force and bending moment analyses. The uniformly distributed load (UDL) of **2.450 kN/m** was converted to an equivalent point load of 1.764 acting at the mid-span. Reaction forces at the supports were found to be :

$$R_A = R_C = 0.882\,\text{kN}$$

Also, the shear force diagram uncovered symmetrical loading with zero net shear at the end supports, ascertaining equilibrium. The bending moment (BM) analysis demonstrated a maximum bending moment of 0.3175kN-m at the mid-span, while the BM at the supports remained zero. More so, the values are within the safe limits for the selected shaft and the dimensions of the frame, substantiating the mechanical design.



Convert the Uniformly Distributed Load (UDL) to a Point Load (PL)

2.450 kN/m × 0.72 m = 1.764 kN

Calculate reaction Ra and Rc.

Take a moment about Ra. (i.e., $\Sigma MRa = 0$)

1.764 × 0.36 = Rc × 0.72

0.635 = 0.72 Rc

Rc = 0.882 kN

Since the load is equally distributed,

Therefore, Ra = Rc = **0.882 kN**

Shear Force Analysis (SFA)

SF at A = Ra = **0.882 kN**

SF at B = 0.882 – 1.764 = **– 0.882 kN**

SF at C = 0.882 – 1.764 + 0.882 = **0**

Bending Moment Analysis (BMA)

BM at A = Ra $\times x$ = 0.882 $\times$ 0 = **0**

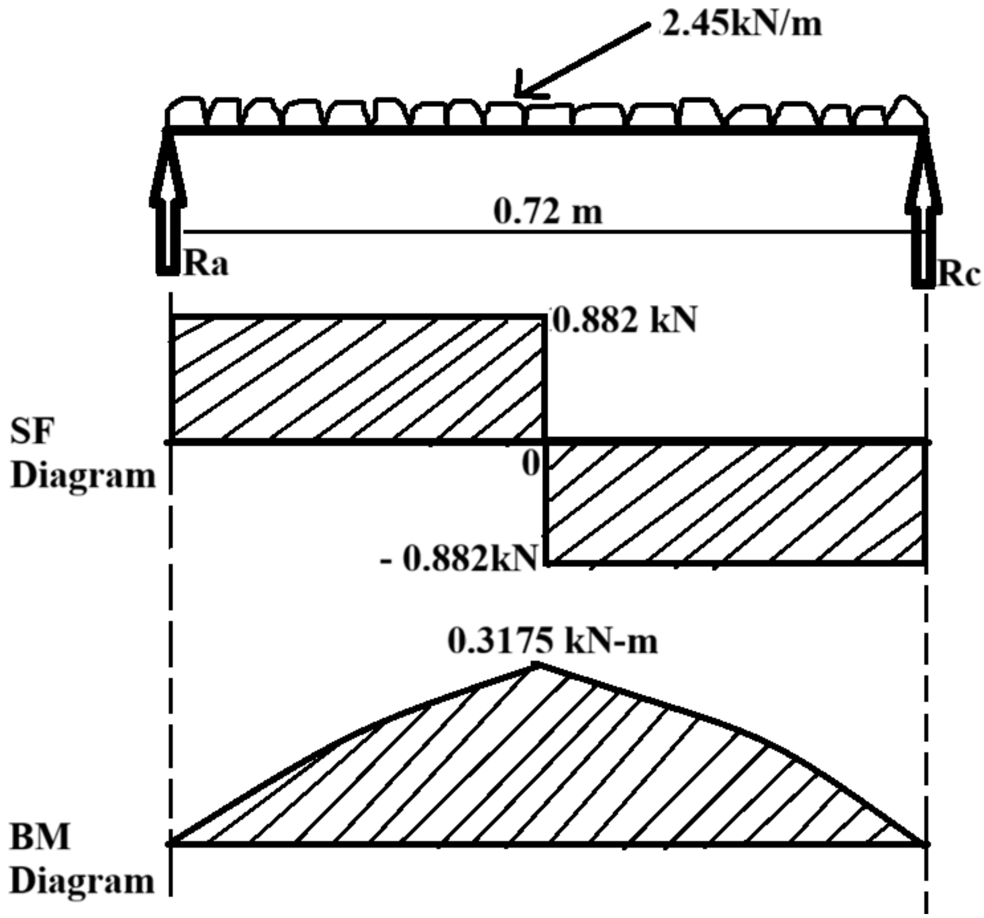
BM at B = Rax – 2.45 $\frac{x^2}{2}$

0.882 $\times$ 0.36 = **0.3175 kN-m**

BM at C = Rax – 2.45$\times \frac{x^2}{2}$

0.882 $\times$ 0.72 – 2.45 $\times \frac{0.72^2}{2}$

0.635 – 0.635 = **0**



3.5 Power and Drive System Performance

The electric drive system comprises a 3HP electric motor, the chain drive, and the sprocket configuration, which performed satisfactorily. The estimated motor torque of 5.94 N · m was adequate to drive the system under the limit load conditions. The reduction of speed was achieved via the sprocket ratio, ascertained the controlled motion and improved the delivered torque at the wheels. The battery system includes two batteries, 12V each, connected in series, providing sufficient power for approximately one hour of continuous operation, achieving the design requirements. However, battery discharge was observed under heavy load for an extended operation, underlining the need for an improved battery management system.

4.0 Conclusion

The design and fabrication of the electric motorized barrow were accomplished via locally sourced available materials and conventional manufacturing processes. The developed product excellently addressed the challenges of the manually operated wheelbarrow by remarkably reducing the human effort, operator fatigue, and danger associated with musculoskeletal injuries linked to manual load transportation. Performance assessment ascertained that the electric motorized barrow could efficiently transport a maximum load of 250kg across different terrain while maintaining suitable speed and stability. In addition, the structural components, fabricated from mild steel with sufficient tensile strength, demonstrate no signs of defects or deformation under load, substantiating the suitability of the design calculations and selection of materials. The electric drive system offers sufficient torque for loaded operation, while the chain and sprocket arrangement ascertained smooth power transmission to the wheels.

Acknowledgement

The authors acknowledge with gratitude the support of the Tertiary Education Trust Fund (TETFUND) through the Institutional Based Research (IBR) scheme, which sponsored the presentation and publication of the research work

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