Design of Low-Cost Vehicle for Nigerian Rural Farmers for Transportation of Farm Produce

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Abstract

The paper highlights various problems associated with the transportation of agricultural farm products by Nigerian rural farmers and discussed the classification of intermediate means of transportations (IMTs) and the common types of low-cost vehicles available. The research led to the design of an improved low-cost vehicle that is designed to be affordable, efficient and easy to maintain using locally sourced materials. The improvement in the design of the low-cost vehicle is seen in it compatibility, provision of roof cover, engine location at the rear, tilting of the trailer container, provision of more comfortable seats and the use of locally sourced materials for it construction.

Keywords

Transportation, rural farming, low cost vehicles, load container and Nigeria

1. Introduction

The benefits of increased production are seriously affected as farmers continuously face the problem of transportation during the post-harvest. The report on the survey carried out by Olawepo R. A. (2010), in a district area in Kwara State, Nigeria, highlighted that one of the constraints in food productivity is the high cost of transportation of farm produce. Fatulu B. (2007), in an extensive research carried out, also highlighted transportation as one of the serious problems facing agricultural development in Nigeria.

The technological efficiency of food farmers was put at 0.82 which shows a significant effect of inefficiency. The inefficiency analysis indicated positive effect of distance, crop diversification and un-tarred type of road on farmer's productivity, while poor level of education among farmers, use of bicycle; trekking and weekly working time negatively affect farmer's efficiency (Kassali R. et al, 2012).

Modes of transportation are means used to move passengers and goods from one point to another and in this case, to move from farm to market/village and vice versa. Roads transportation are essential for the sustainability of agricultural production in Sub-Saharan Africa as it impacts positively factors such as mobility (Riverson J.D.N. and Carapetis S., 1991). Tunde A. M. and Adeniyi E. E. (2012) examines the effect of road transport on agricultural development in a Local Government Area in Kwara State and the findings revealed that the high cost of transportation of agricultural produce really affects the rural farmer's income.

The study carried out by Ajiboye A. O. and Afolayan O. (2009), revealed that improve transportation will no doubt encourage rural farmers in working harder to increase their production yield, add value to their products, reduced wastages and empower the rural farmers. A well designed, durable and multifunctional low-cost farm vehicle as an intermediate means of transportation can easily solve the problem of transportation problem faced by the Nigerian rural farmers thereby reducing the crop wastages as being witnessed. Commercial transportation that covers the rural areas for the transportation of farm produce to the markets/agro-allied industries are not usually frequent and cost so much to the farmers due to bad un-tarred and narrow road network. The rural farmers being attributed with inconsistent and low-income earners find it difficult to have a vehicle of their own to transport large produce.

Also, there are no companies or facilities in Nigeria currently producing farm vehicles and engines as engines are currently being imported. Diesel powered engines are normally being used by the farmers for the pumping of water from streams and rivers to irrigate the farm lands. Also, single axle engines are readily available in the market, but the rural farmers lack or are deprived the basic technique or ideas of harnessing these engines and use it for the transportation of farm produce and other implements.
Among the challenge that is witnessed in the design, is knowing the actual

design needs of the farmers, selection of appropriate material (locally sourced) for the construction, design calculation, modelling and analysis to ensure the design suit the particular purpose and bearing in mind that it must be affordable, durable, easy to operate and maintained.
Dennis R. and Smith A. (1995) classifies the Intermediate Means of Transports as illustrated in Figure 1.

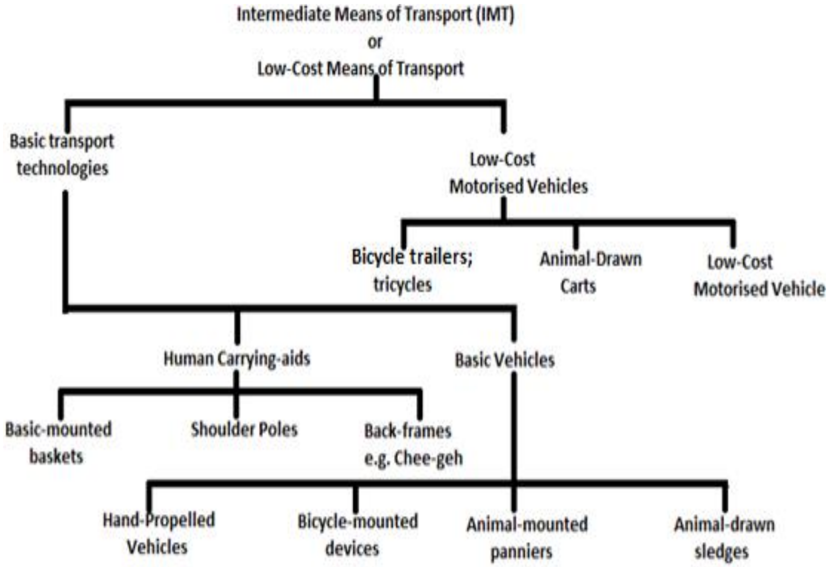

Figure 1: Classification of Intermediate Means of Transport (Dennis R. and Smith A., 1995).

Studies from the International Labour Office (ILO) and United Nations Centre for Human Settlements (Habitat) (1998) and Riverson J. D. N. and Carapetis S. (1991) come up with the common types of low-cost vehicles of transporting passengers and goods; which are quickly discussed in brief below.

- Motorcycle and sidecar: This is made up of a single-wheeled load-carrying attachment that is fixed firmly to one side of a regular motorcycle.
- Motorcycle based three-wheeled vehicles: These are made up of regular motorcycles that are converted using an extended chassis, back

axle two-wheeled attachment and bodywork construction

- Motorcycle and trailer: This is made up of two wheeled load-carrying trailer that is attached to the back of a motorcycle with the help of a hitch which permits it to be attached and detached easily and quickly.
- Four-wheeled conversion of motorcycle: This type of motorcycle conversion consists of the chassis and two-wheeled axle load carrying body, well attached to the motor cycle, where by the load is well distributed on both side and behind the motorcycle.
- Small diesel-engine three-wheeled vehicles: These are powered by single cylinder diesel engines made up of specially built chassis with single front steered wheel, two rear wheels and load-carrier located behind the driver.
- Commercially produced three-wheeled vehicles: These are specially built three-wheeled vehicles for commercial purposes, meaning that they are commonly used for commercial transportation.
- Small diesel-engine four-wheeled vehicles: These types of vehicles are made up of four-wheeled chassis and with load-carrying bodywork. This is usually driven by small diesel engine that is commonly a single cylinder engine.
- Single axle tractor and trailer: This type of vehicle is usually made up of two-wheeled load carrying trailer attached with the means of a hitch to a single axle tractor.

The aim of this project is to design a simple multi-functional low-cost farm vehicle durable enough to convey a substantial amount of load and will be affordable for the rural farmers who are saddled with the problem of transportation and the objectives are:

- To conduct a research on a low-cost farm vehicle. Researching the existing method of farm produce transport and designs, in other to come up with an improved design.
- To design and analyse the frame of the low-cost farm vehicle base on the maximum payload it may be subjected to, thereby ensuring that the frame is well designed and can withstand the maximum payload.
- Lastly, to recommend the final design as an improved multifunctional low-cost design that will be affordable, easy to operate and maintained.

2. Methodology

In achieving the stated aim of the project of providing a suitable and improved design of low-cost vehicle for Nigerian rural farmers for transportation of their farm produce, a literature review on previous works on Nigerian rural agriculture and transportation was carried out. These reviews were sourced from various mediums from printed or online textbooks, journal papers, published and unpublished thesis. This gave the background knowledge and idea required to have a suitable and acceptable design.

With the background knowledge, it was followed by a concept design in the form of sketches/hand drawing; material selection and hand calculation taking into account the design requirements and parameters. The material selection mind-set is based on popular and easily accessible material in the rural areas, was done to aid in initial calculation based on the mechanical properties of the selected materials.

The actual material selection for the analysis of design was based on the use of Cambridge Engineering Selector (CES) software. With the software, it aid at looking at the vast material universe and coming up with the preferred and most suitable materials suiting certain properties after some compromised must have been made as regards to material properties and cost.

The above stages are then followed with a 3D modelling of the actual design, using a computer aided design tool (Solidworks software). The modelling was done using the design parameters and dimensions obtained from the design concept/sketches. A conclusion was drawn out from the discussion and recommendations were made.

3. Design and Modelling Process

3.1 Concept Design

The concept design came up as a result of the farmers demand for a means of transport not only for transporting the farmers but also for transportation of farm implements, farm produce, pulling or driving of other farm processing machines and implements, coupled with the fact that the means of transport must also be affordable, durable and easy to maintain.

In view of the farmers demand, a design concept shown in Figure 2 of improving the existing design came to light. Improving the design of single-axle tractor and trailer as shown in Figure 3 and 4, thereby improving the design and meeting the farmers demand by:

i. coming up with a design of making the single-axle tractor and trailer a whole piece and making the design more compact by reducing the size (total length and width);
ii. providing a roof cover to protect the driver from harsh weather conditions (rainfall and sunlight) knowing that Nigeria is in the temperate region with an average temperature of 26.4^{0}C;
iii. locating the engine at the rear of the vehicle in a way of making the vehicle more compact;

Figure 2: single-axle tractor and trailer
http://chuckdavid.photoshelter.com/image/I0000XI1WdzGWQ50

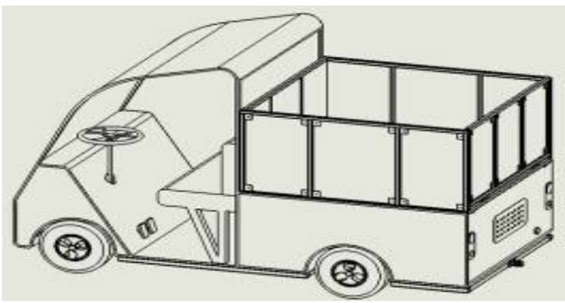

Figure 3: Design sketch of improved farm vehicle

Figure 4: Single-axle trailer
http://www.zombiehunters.org/forum/viewtopic.php?f=100&t=96338&start=24

iv. making it possible for tilting of the trailer not only for off-loading farm produce but also to provide an access to the engine;
v. providing a comfortable driver and passenger seat;

Using locally available materials for the construction of the vehicle body such as plywood.

3.2 Hand Calculation

The basic assumption in the improved farm vehicle design is to make it compact, of which the vehicle total length should not be more than two meters and the wheel base centre to centre distance not to exceed 1200mm. The trailer container size is not to exceed 1000x 1000 x 500 mm, in terms of its length, width and height.

3.2.1 The Trailer Container

The trailer container in Figure 5 internal dimension is given as 965 x 938 x 466 mm.

Calculating the internal volume of the trailer container, V_t
V_t = internal length x internal width x internal height
$V_t = (0.965 \times 0.938 \times 0.466)\ m^3 = 0.422 m^3$

The internal volume of the trailer container is $0.422m^3$. Any farm produce such as coconut, maize cob etc. are expected to feel this trailer space. Coconut with husk varies in sizes (or weight), always within the range of 8-15kg, and density of 750 ± 56 kg/m^3

For small coconut, having a mass of 8kg and density of 750 kg/m^3, the volume, Vsc= 8/750 = $0.0106m^3$

The number of small coconut that will fill the trailer container is given as:

No. of small coconut = volume of trailer container/ volume of one small coconut

No. of small coconut = 0.422/ 0.0106

No. of small coconut to fill trailer container = 39.81

Therefore, the number of small coconut to fill the trailer container is approximately 40.

The mass m_s of 40 small coconut on the trailer container is given as:

m_s = No. of small coconut x mass of one coconut =40 x 8 = 320kg

The weight W_s of the 40 small coconuts on the trailer container = 320 x 9.81 =3139.2N (g= acceleration due to gravity =9.81 m/s^2)

For large coconut, having a mass of 15kg and density of 750 kg/m^3, the volume given as: V_{lc}= 15/750 = $0.02m^3$

The number of large coconut that will fill the trailer container is given as:

No. of large coconut = volume of trailer container/ volume of one large coconut

No. of large coconut = 0.422/ 0.02

No. of large coconut to fill trailer container = 21.1

Therefore, the number of large coconut to fill the trailer container is approximately 21.

The mass m_l of 21 large coconuts on the trailer container is given as:

m_l = No. of large coconut x mass of one coconut = 21 x 15 = 315kg

The weight W_l of the 21 large coconuts on the trailer container = 315 x 9.81= 3090.15N

For maize cob, having a mass of 0.349kg and bulk density of $282.38kg/m^3$, the volume Vm = 0.349/282.38 =$0.00124m^3$

The number of maize cobs that will fill the trailer container is given as:

No. of maize cobs = volume of trailer container/ volume of one maize cob

No. of maize cobs = 0.422/ 0.00124

No. of maize cobs to fill trailer container = 340.32

Therefore, the number of maize cobs to fill the trailer container is approximately 340.

The mass m_m of 340 maize cobs on the trailer container is given as:
m_m = No. of maize cobs x mass of one maize cob= 340 x 0.349 = 118.66kg
The weight W_m of the 340 maize cobs on the trailer container = 118.66 x 9.81 = 1164.05N
Using the weight of small coconut (Ws) been the maximum weight here, to calculate the stress and strain on the plywood platform,
Stress (σ_p) = force (Ws) / Area (Ap) at Ws= 3139.2N
Area of platform (Ap) = 0.965 x 0.938 = 0.905m^2
Stress (σ_p) = 3139.02/ 0.905 Stress (σ_p) = 3467.879N/m^2
Taking young modulus of plywood (Ep) as 6.9GPa, the strain on the platform
$\varepsilon_p = \sigma_p$ / Ep = 3467.879 / (6.9 x 10^9) = 5.026 x 10^{-7}
The strain on the plywood container platform is considerably low and the applied load will only have little effect on the platform.

3.2.2 The Vehicle Chassis

The vehicle chassis is to be designed and enabled to be bolted to the vehicle body. The vehicle chassis is assumed to be constructed from a 30 x 30 x 2.6 mm square steel pipe, which is readily available in the Nigeria market. The chassis sketch is shown in the Figure 6.

The total length of 30 x 30 x 2.6 mm square pipe required for the chassis is 9.919m, approximately 10m. The surface area of the chassis (A_{ch}) = 9.919 x 0.03 A_{ch} = 0.296m^2

The total load (weight) that will be acting on the vehicle chassis surface comprise of the weight from vehicle body, trailer container, engine, exhaust pipe, bearing and bearing housing, engine and shaft pulleys, rear shaft, trailer load, other smaller parts load and the driver's own weight (put at an average of 120kg). The total load acting on the vehicle chassis is estimated and put at 610.068kg.
Therefore, the total weight acting on the trailer chassis (W_{ch}) = 610.068 x 9.81 = 5984.774N
The stress on the chassis (σ_{ch}) is given as:$\sigma_{ch} = W_{ch} / A_{ch}$ = 5984.774 / 0.296 = 20218.831N/m^2σ_{ch} = 20.219KN/m^2
Taking a young modulus of chassis steel material (E_{ch}) as 210GPa
The strain on the chassis, ε_{ch} = 20218.831 / (210 x 10^9)= 9.628 x 10^{-8}
The chassis will be able to withstand the applied load as the strain on it, is also comparably low.

3.2.3 Engine Specification Justification

The Honda engine GX340 that have been chosen and mounted on the chassis having specifications shown in Table 1, can be justified by calculating the power and torque required to move the vehicle. Assuming the total mass of the vehicle is put at 700kg, and is to be moved at a speed (V) of 1m/s. Calculating for power (P), which is the engine ability or capability to act,

$$P = FV \qquad (1)$$

where F= total weight of vehicle (700 x 9.81= 6867N); P= 6867 x 1= 6867Nm/s

Calculating the measure of force required that will cause the vehicle to move (torque, T), T= (HP x 5252) / rpm

Where rpm= revolution per minute= 2500 (given in engine specification), 5252= constant

T= (9.206 x 5252) / 2500 = 19.34Nm

From the results of power and torque obtained, it will be noted that these are less than that of the engine specification with the engine having power of 10.7HP and torque of 26.4Nm at 2500rpm.

3.3 Modelling/Actual Design

3.3.1 Chassis: The design modelling of the design concept was done using Solidworks software. The modelling started by fashioning the vehicle chassis based on the design parameters required. The chassis outlined drawing/sketch is shown in Figure 6; the actual modelling of the chassis and drive line assembly is shown in Figure 7. The arms/shafts supporting the front tires on which the steering arms are connected to made it easy to manoeuvre the two front tires with the steering wheel via the steering rod. Almost at the middle and towards the rear end of the chassis, an Honda GX340 single cylinder engine is mounted on two bars with four 12mm bolt. And immediately after it, is a location for the rear shaft rod that carries the two rear tyres and is mounted to the chassis with the help of bearings fitted in bearing housings and bolted to the chassis using 8mm bolts.

3.3.2 Vehicle body:

The vehicle body as shown in Figure 8 is modelled based on the required specifications of making the vehicle compact, not exceeding two meters in length and one meter wide. And also build to be able to shield the driver against harsh weather condition and be able to transport considerable amount of load as to make the transportation more comfortable as previously experienced by the rural farmers.

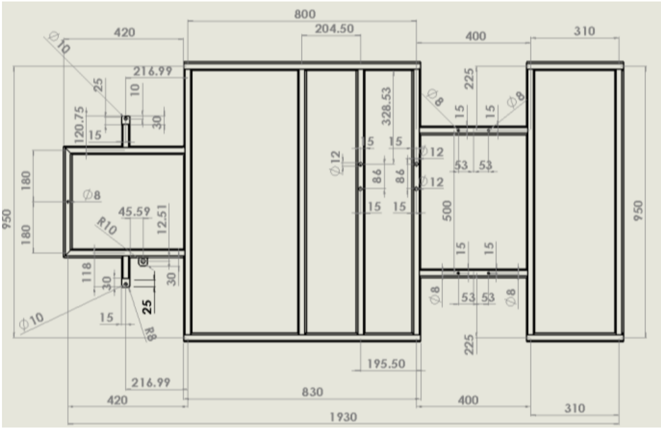

Figure 6: The vehicle chassis outline sketch drawing

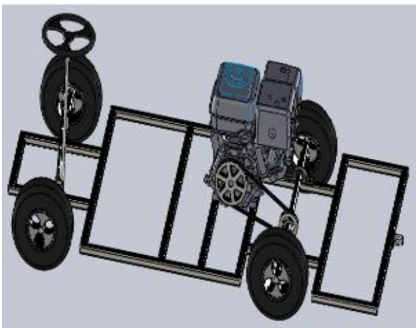
Figure 7 Chassis and drive line assembly

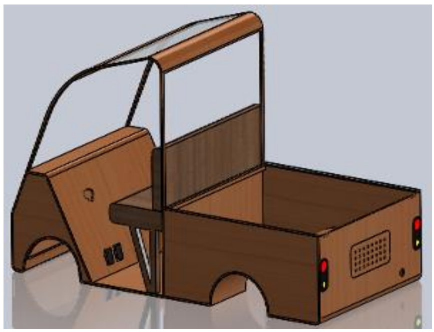
Figure 8 Vehicle body

Not forgetting the main aim of designing an affordable farm vehicle, the vehicle body is modelled in such a way to make it easy for construction by which plywood will be highly suitable for the vehicle body. The seat in the vehicle is also modelled to accommodate extra passenger.

3.3.3 Trailer container:

The trailer container is modelled not to exceed one meter in length and width and also not exceeding half meter in height. The container is modelled using 20 x 20 x 2mm steel pipe of which plywood are now fix to its sides and platform as shown in Figure 5. The container is designed to have a door for easier loading and unloading of goods and also designed to be raised up so as to be able to have a clear assess to the engine when need arises. The plywood material should be seasoned and if possible painted to ensure it is not damaged due to atmospheric moisture and also to add some level of good appearance and finish.

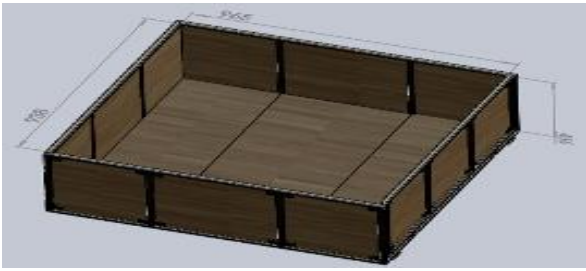

Figure 5: Internal dimension of trailer container

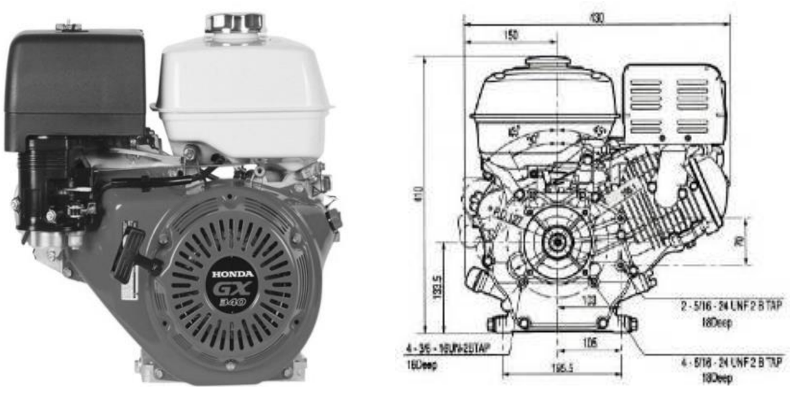

Figure 9: Engine image and its Schematic diagram (http://m.engines.honda.com/models/model-detail/gx340 , 30 April, 2014).

3.3.4 Vehicle engine:

A Honda GX340 single cylinder engine that can also be used to drive other farm implements is mounted on the chassis to drive the rear shaft on which the rear tyres are mounted to. This is made possible via the engine assembly line consisting of the engine pulley connected to the shaft pulley with the use of a drive belt.

The exhaust from the engine is removed via an extended exhaust pipe that comes out at the rear of the vehicle body. The Power output of the Honda Engine GX340 is given as 8.0 KW (10.7 HP) at 3600 rpm, net torque of 264 Nm at 2500 rpm, fuel tank capacity of 6.1 litres, engine dry weight of 31.5 kg with engine total length of 407 mm, width of 485mm and height of 449 mm. Figure 9 shows the engine and its schematic diagram. The main vehicle assembly image and sectional views are shown in Figures 10-13.

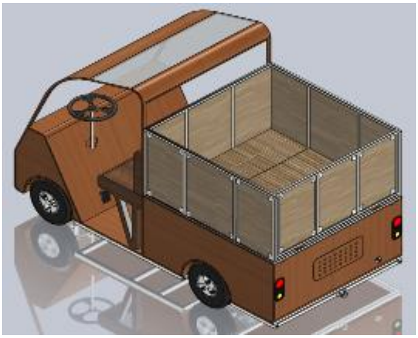

Figure 10: Main vehicle isometric view

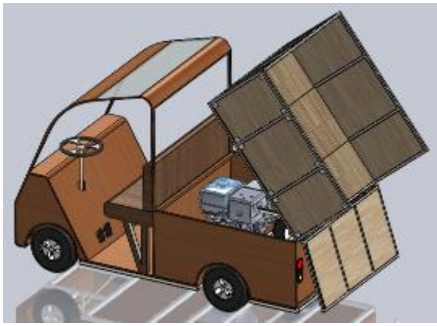

Figure 11: Trailer tipping vehicle image

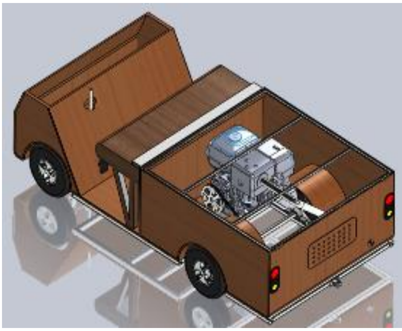

Figure 12: Top plane sectional view

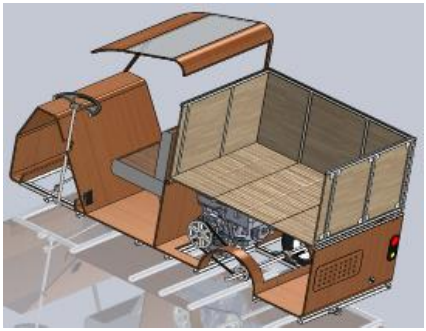

Figure 13: Front plane sectional view

3.4 CES Material Selection

Keeping in mind the main objective, of designing a low-cost farm vehicle for rural farmers that is not only affordable but also efficient and easy to maintain, means that to meet this objective, the bulk of the material required for the construction of the farm vehicle must be sourced locally. The body of the vehicle and the trailer platform and are selected to be of plywood with the trailer frame made from 20 x 20 x 2mm square steel pipe and the chassis constructed from 30 x 30 x 2.6mm square steel pipe. The trailer frame and its body could also be built from bamboo as it has good property of good strength at low weight, easily available to the rural duellers and considerably cheap.

The Cambridge engineering selector is a very useful tool in the selection of engineering material to best suit specific application. It contain numerous engineering material in its data base which range of materials can be selected based on certain specifications that cut across mechanical, physical, chemical and electrical properties. The selection of material is arrived at after a detailed screening and compromised has been reached based on cost, density and other parameters. Good use of the software makes it possible to arrive at appropriate material that fit certain application and ensuring that a component does not fail with time.

The selection of material for the chassis and the trailer frame is done in four stages using the CES material selector. The first stage in the selection of material involves setting a limit of parameters (such as density, price, young's modulus and yield strength) for the selection of the metal material from the CES material universe. The limits of parameters set for the metal material is shown below.
Density: 7600-7900kg/m^3
Price: 0.30-0.40GBP/kg
Young's modulus: 200-220GPa
Yield strength: 400-550MPa
The variables are set in a way as to have a material of good density, high yield strength to be able to withstand the applied load and to be within an acceptable cost price. The results obtained from this first stage brought the number of metals from the material universe from 1883 metals down to 59 metals.

In the three remaining stages, graphs of density (kg/m^3) vs. Price (GBP/kg) in Figure 14, Density (kg/m^3) vs. Young's modulus (GPa) in Figure 15 and Young's modulus (GPa) vs. Yield strength (MPa) in Figure 16 were plotted. A line of slope 1 cuts across the graph, in a way of analysing the viewing the material trend in the graph. This is done in other to make it easy for the selection of the appropriate material that best serve the required purpose.

The first graph shown in Figure 14 revealed that most of the material falls on a similar density range with their price varying accordingly. The arrangement of the materials in an ascending order of price, makes high strength low alloy steel YS350 the least expensive, followed by carbon steel AISI family (1060annealed, 1060 normalised, 1040 normalised, 1030 tempered, 1040 as rolled, 1050 annealed, 1050 normalised, 1040 tempered, 1050 as rolled and low alloy steel 4140 annealed) and making ferrite-bainite steel YS330 hot rolled the most expensive. Also, the arrangement of the metals in an ascending order of density gives shows that cast iron, EN GJN HV350 has the least density with the carbon steel AISI family listed above having average density and Ferrite-bainite steel YS330 still having the highest density.

After due analysis, consideration and compromise, it can be seen that cast iron is not suitable in this application base on the type of form and required property of the material. As a result, the most applicable material suitable for the chassis material base on form and price falls within the carbon steel family and high strength low alloy steel. The carbon steel has an acceptable young's modulus and yield strength that is able to withstand the required application and falls within the price range that is affordable. Most of the metals (AISI 1030 tempered and 1060 normalised and annealed etc.) are used in general construction, automotive, axles, springs, gears and general mechanical engineering works. The high strength low alloy steel YS350 cold rolled is another suitable material as it is used as cross member, and longitudinal member for the chassis. The most expensive material in the group (Ferrite-bainite steel YS330 hot rolled) is normally used as cross beams, longitudinal beams and car body and may also be suitable for the application. Most of the square pipes needed in the construction of the vehicle chassis and trailer frame are available in Nigeria in different sizes and are made from carbon steels. The vehicle body is proposed to be made from plywood as a way of reducing the production cost of the vehicle. The plywood is a readily available material also in different form grades and thicknesses, with the price varying according to the grade and thickness. Because plywood is a material that has less resistance to atmospheric moisture, it can be treated or seasoned and painted as a way of protection and good aesthetic finish. The plywood has a density within the range of 700-800kg/m3 with a price range of between 0.208-0.636GBP/kg with moderate strength which made it suitable for the required purpose.

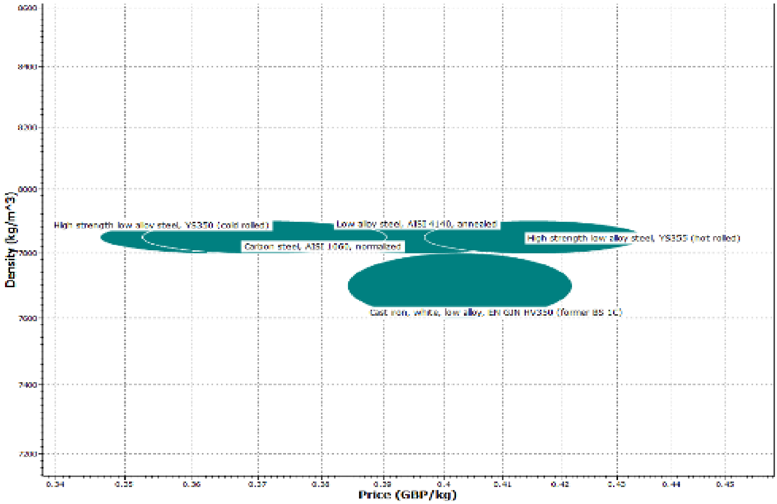

Figure 14: Graph of Density (kg/m^3) vs. Price (GBP/kg)

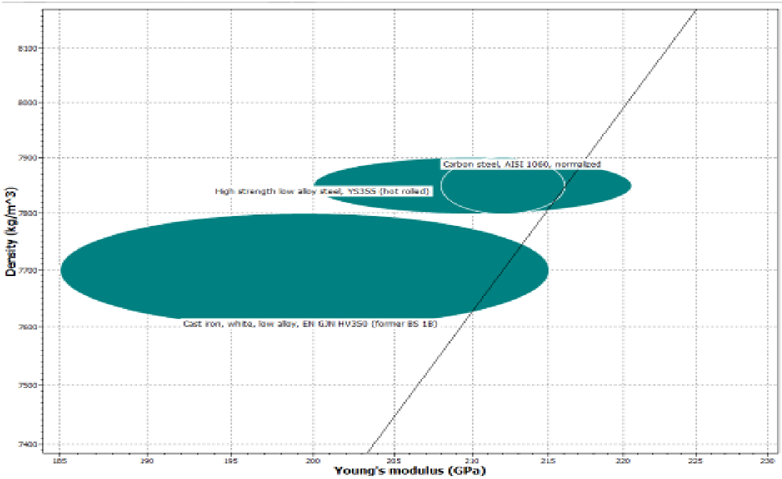

Figure 15: Graph of Density (kg/m^3) vs. Young’s modulus (GPa)

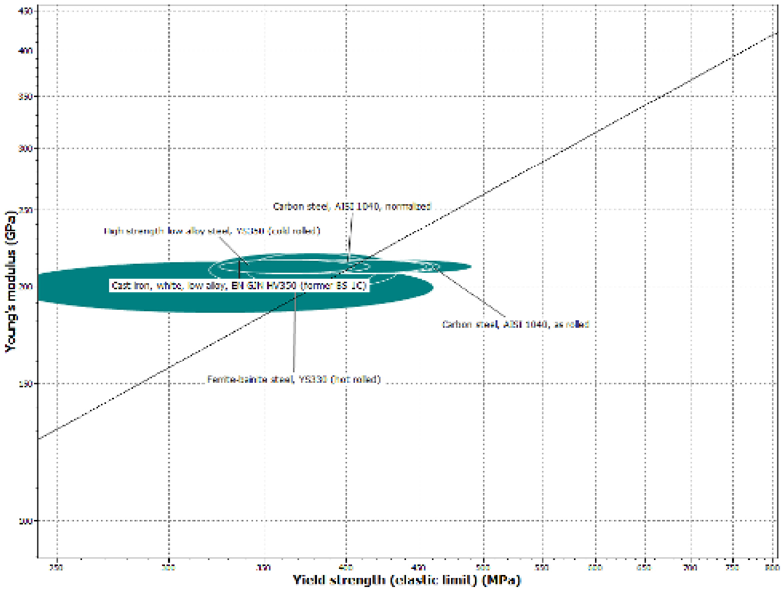

Figure 16: Graph of Young’s modulus (GPa) vs. Yield strength (MPa)

4. Conclusion and Recommendations

The research has clearly revealed that it is possible to design for manufacture, a low-cost farm vehicle that is aimed at alleviating Nigerian rural farmer’s ordeals as regards to transportation of farm produce. Rural farmers currently face the problems of crop wastages due to unpredictable and inefficient transport and increase in transport fares, energy exhaustion and time wastage in transportation of farm workers and farming implements.

The static finite element analysis results obtained for the trailer shows that the models are well designed to withstand the maximum payload that the vehicle may be subjected to when high yield strength material is employed in the construction of the trailer and vehicle chassis.

The design of the low-cost vehicle can be regarded as successful, as it has made use of low price square hollow pipe for the construction of chassis and trailer frame, plywood for vehicle body and single cylinder Honda engine to drive the farm vehicle.

Recommendations to the design are highlighted below:

(i) Reduction of vehicle mass: high yield strength and low density material other than plywood, such as plastic could be used as vehicle body and polyester material as roof as a way of reducing load on chassis and increasing the vehicle efficiency.

(ii) Tipping of container: the trailer container can be designed to tip effortlessly during unloading by attaching a tipping device to the trailer frame.

(iii) A prototype of the design can be constructed with recommended Honda engine GX340 mounted and container loaded to evaluate the efficiency of the farm vehicle.

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