DEVELOPMENT OF BICYCLE AND MOTORCYCLE CARRIAGE FOR GOODS MOBILITY IN RURAL AREAS OF NIGERIA

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ABSTRACT

The challenges of carrying agricultural loads and forestry products were rightly identified as essentially the rural dwellers burden. Little efforts have been made to have an adaptive mobility frame (attached to bicycle and motorcycle) to carry goods and products from the point of harvest to the point of sales (the markets), a situation that leads to systematic rot of agriculture products on the farms, leading to low revenue and productivity of the rural people. *Therefore, the goal of this research is to* develop an improved carriage (trailer) to bicycle and motorcycle for goods mobility in rural areas of Nigeria. The design criteria for these trailers include: lightness in weight; ease of usage; flexibility; adaptability with various bicycle and motorcycle types; low cost of engineering materials, durability and availability of materials; and it is required that the trailer carries 200 kg load on smooth road (tarred and untarred). Factors considered for this design include; weight of the rider, weight of bicycle and motorcycle, type of road, type of load and factor of safety. Three different trailer designs were developed for the bicycle namely fixed plate design (FPD), convertible plate design (CPD) and wire mesh design (WMD), while the motorcycle trailers developed are the fixed plate design (FPD) and the convertible plate design (CPD). The hitch system used for the WMD bicycle trailer was a conventional universal joint and collar attached to the trailer front frame and the hitch system for the bicycle and motorcycle FPD and CPD comprises an annular of heavy duty cylindrical cone housing and a bolt. These designs are due in part to their simplicity, availability and ease of replacement for rural dwellers. Preliminary evaluations have shown satisfactory performance based on the load carrying capacity; stability of the trailer, bicycle and motorcycle turning ability; comfort of the operator and ease of disassembling the hitch system. A proper usage of the trailers presented in this study will boost the health and wealth of farmers and other rural dweller users.

Keywords: Bicycle, frame, hitch, motorcycle, trailer

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INTRODUCTIO

Transport refers to both motorised and non-motorised modes used for movement of people and/or goods (e.g. bicycles, motorcycles, and cars). It is an essential element in development and it gives the social, economic and political interaction that most people take for granted (Dinye, 2013). Transportation is a non-separable part of any society. It is therefore a major factor in all economic activities (Ajiboye and Afolayan, 2009). An efficient transport system offering cost, time and reliability advantage permits goods to be transported quickly (Tunde and Adeniyi, 2012).

Rural transport involves many types of movement for a wide range of purposes both within villages and beyond. The purpose of the travel may relate to the household obtaining water, fuel, and food, agricultural activities such as tending and marketing crops and livestock; or a wide variety of socioeconomic activities which include; education, religion, recreation, health and employment. Journeys may have multiple purposes. Different means of transport may be appropriate depending on available infrastructure, purpose, distance, gender, and age.

Although human carry loads of 50 kg for short distances, loads of 10-20 kg is more normal. The comfort of carrying these can be increased with simple technologies such as poles, shoulder yokes or back packs. Carrying is flexible, requires little infrastructure, and is the transport means of choice for light loads and very short distances. It may be the only realistic option in difficult environment (such as those with mud, slopes, streams or dense vegetation). Simple wheeled devices such as wheel barrows, hand cart and trolleys increase human transport capacity. Depending on the environment (ground surface and slope); these can comfortably carry 50-100 kg. Balanced hand carts (with most weight on the wheels) are more comfortable than wheel barrows with one forward wheel. Wheel barrows can operate on smaller paths but need two hands to operate them. Carts, barrows and trolleys are easy to load and pack and are good for short or intermittent journeys (100-2000 meters).

In developing countries, vehicle ownership is low per capita; dependency on public transport is high but insufficient. This implies that few rural people own cars and mobility mainly involves walking, intermediate means of transports (IMTs) and public transport. A high proportion of the poor rural people walk or use non-motorised transport, particularly for journeys less than 5-8 km (Starkey and Hine, 2014). Poor rural people often cite the need for better transport (roads and transport services) as key investments that would improve their lives (Riley and Bathiche, 2006; Odoki *et al.,* 2008). Rural transport services are often provided by informal sector entrepreneurs using buses, trucks, pickups, 'rural taxis' (minibuses or estate cars), motorcycles, bicycles, tricycles, animal drawn carts or pack animals. In many countries, IMTs (including motorcycles) provide most of the transport between villages and markets. National transport authorities tend to neglect the importance of non-motorised IMTs for poor people; however, bicycles and work animals provide crucial mobility to access markets, healthcare and schools (Oyesiku, 2016). They also provide employment opportunities, including bicycle taxi operations and bicycle repairs.

IMTs range from simple wheelbarrows and hand-carts, to bicycle-based and motorcycle-based technologies and include 2-wheel carts or 4-wheel wagons pulled by oxen, buffaloes, donkeys, mules, horses or camels (Riverson and Carapetis, 1991; Starkey, 2002). IMTs provide local transport, carrying people and goods around villages (and towns) and some also provide transport between villages and markets, either for individuals or as informal transport services. Most rural transport services are 'mixed', with passengers and small freight, in light trucks, minibuses or buses (Starkey, 2007). On many rural roads, IMTs constitute the majority of the traffic and together they may carry large numbers of people and significant quantities of freight (Starkey *et al.,* 2013). In many countries, motorcycles are becoming the most common vehicle on rural roads.

The role of African women in porterage is remarkable: they may spend over 4 hours per day solely on transport and move approximately 50 kg per day (Philpott, 1994). Porter, (2002) reported from African surveys that women typically account for about 65% of all household time spent in transport activities and 66- 84% of all effort; they undertake 71-96% of all domestic travel. Many women will also be carrying a baby on their back in addition to these loads. Health problems associated with head-loading may include backache, head and chest pain, deformation of the spine and osteo-arthritis of the soft tissue of the knee (Porter *et al.,* 2007). Some of the health issues may even have inter-generational impacts such as miscarriage, damage to the unborn foetus and reduced quality and quantity of breast milk in nursing mothers etc.

In most rural areas of Nigeria, bicycles and motorcycles are the most means of transportation. The bicycle is a unique type of intermediate means of transportation that is used to transport both passengers and goods while motorcycle is a unique type of motorised transport that also transport passengers and goods. It should be noted that rural agricultural goods are mostly carried to market place by head loading and hand loading. In addition, most riders of bicycles and motorcycles usually carry goods in unsafe conditions; hence, the need to develop a trailer to be adapted to bicycle and motorcycle for goods mobility.

Cycle trailer technology was a common sense solution to carrying loads or head loading. The problem of carrying loads or head loading was rightly identified as essentially the rural dwellers' (mostly women) burden and it is the main goal of this research study to propose a solution that will completely be in tune with the immediate economic, social and cultural environment of the rural dwellers in Nigeria. The main goal of this research work is to develop an improved carriage to bicycle and motorcycle for goods mobility in rural areas of Nigeria.

Existing Carriage Solution

In Nigeria, the inhabitants of rural areas are mostly farmers engaged in agriculture producing goods such as palm oil, yam, gari, kola nut, rice, beans, cocoa, etc.; that are consumed in the cities and most of the agricultural raw materials used by the industries. Majority of the goods to be transported are by nature often bulky, low price and perishable. Poor accessibility in the rural areas poses a great challenge to actualize rural development efforts in Nigeria through agricultural reforms, as it has continued to make most of the rural areas to find difficulties in accessing markets for their produce and vice versa (Ajiboye and Ayantoyinbo, 2009; Yaro *et al.,* 2014). Typical scenarios of moving goods in rural areas are depicted in the Figures 1, 2, and 3 below.

Figure 1: Head loading of agricultural product

Figure 2: Loading of bicycles

Figure 3: Loading of motorcycles

In many Asian countries, non-motorised bicycles (two wheelers) and three wheelers are common sights, employing special adaptations to the vehicles for goods transport, hawking or taking passengers. Bicycle trailers were developed by Practical Action (a non-governmental organisation) in Sri Lanka and then adopted by Practical Action East Africa (Kenya) and now in Nepal and Zimbabwe (Michael, 1986). Practical Action has worked on a range of transport technologies that address different transport needs, such as Ox carts, extended load carrying bicycle, aerial runways, bicycle taxis, bicycle ambulances, wheelbarrows, low cost wheel making, animal harness, low cost road construction and bicycle trailers.

Bicycle trailers are used for transporting goods, fuel, water and harvested products where other means are expensive. Trailers allow people carry three times as much as with a bicycle which allows people carry load in an unsafe manner (Michael, 1986). It has been used for mobile store and kitchen and mobile library for school children both in Sri Lanka. It has also been used for an ambulance (figure 4). Cycle trailer was reported as a reasonable but inappropriate technology (Mohammed, 1997). This was due to the overestimated maximum load of 200 kg which resulted in the trailer collapse. Furthermore, the technology failed to win popular recognition because it was unaffordable and not entirely relevant to the needs of its intended users.

Figure 4: Bicycle ambulance (Wallrap and Faust, 2008)

Many of the bicycle complements are multiple-use as well, and are marked as such. However, conditions in many developing countries require bicycles that can safely transport people and heavy cargo over unpaved roads. Bicycles, because of their light weight, put less wear and tear on roads than motorised vehicles, and this translates into lower road maintenance and repair costs. Another advantage is the zero emission level which is mostly encouraged globally. In addition, motorcycles have become a major means of transporting goods and humans in rural areas in which Nigeria is not an exception. Attachment of trailer to bicycle and motorcycle will help in the movement of mostly agricultural products.

Several configurations of bicycle trailers have been reported in the literature. Practical Action reported two different designs for bicycle trailer frame namely a frame design made from tubular bar and a frame design made from angle bar. The trailer was hitch to the bicycle above the rear wheel (under the seat). Also the wheel of the trailer was strengthened with standard bicycle tyres so as to carry heavy loads. A notable research on bicycle trailers is that of Ayre (1986) as depicted in Figure 5. Most bicycle trailers developed have since been modelled after these configurations (Figure 6). Much of the motorcycle trailers developed also followed the configurations shown in Figure 5.

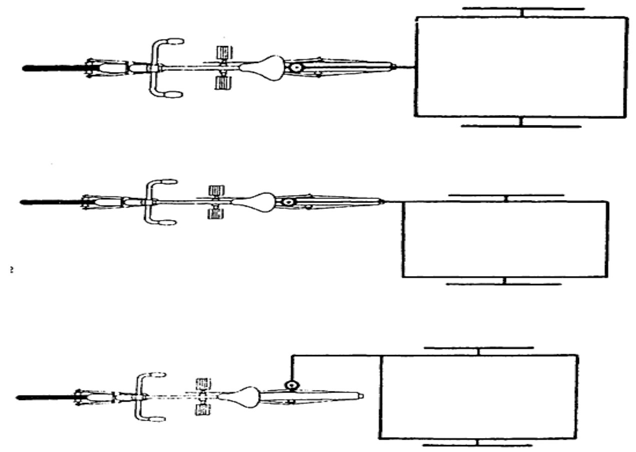

Figure 5: Configurations of bicycle trailer designs (Ayre, 1986)

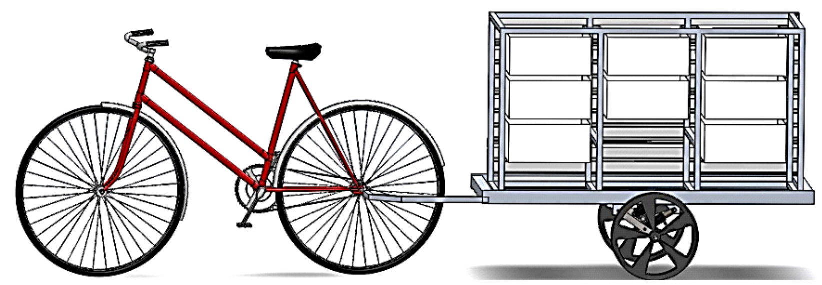

Figure 6: Bicycle trailer designed for Higher Ground Farms (Hastings et al, 2016)

Materials and Methods

Three different trailers were developed for bicycles while two trailers were developed for the motorcycles. For bicycles, there was a fixed plate design (FPD), convertible plate design (CPD) and wire mesh design (WMD), while the motorcycle trailers developed are the fixed plate design (FPD) and the convertible plate design (CPD). These improved trailers were expected to be light in weight; easy to use; flexible; adaptable with various bicycle and motorcycle types; made of low cost, durable and locally available materials; and able to carry load of 100-200 kg on untarred and tarred roads. Some of the variables used in the design include: Bicycle wheel diameter d_w – 0.74 m; Motorcycle front wheel diameter d_{fw} – 0.57 m; Motorcycle rear wheel diameter d_{rw} – 0.58 m; Bending stress of mild steel (σb) – 155×10^6 N/m^2
Shear stress of mild steel (S_s) - 40×10^6 N/m^2

Design

Trailer Capacity

In determining the trailer capacity, it was assumed that the length and width will accommodate two 50 kg jute bags each.

1. **Width of trailer:** Since the width of a 50 kg jute bag is 0.4 m, it implies that a width of 0.8 m will be adequate for the trailer
2. **Length of trailer:** The length of a 50 kg jute bag is 0.8 m; hence, a trailer length of 1.6 m will be adequate for two 50 kg jute bags.
3. **Height of trailer:** The depth of a 50 kg jute bag is 0.2 m; hence, a trailer height of 0.4 m will be adequate for two 50 kg jute bags.

Trailer Chassis

The design load will be carried by the base of the trailer. The base was divided into 8 sections. For ease of construction, the members of the base of the chassis are of the same dimension (i.e. 0.4 m long). In determining the dimension of the hollow mild steel and angle iron which will sustain the design load, it was assumed that the design load will act as a point load equally shared on 4 members of the frame. The bending moment was estimated from equation 1.

$$\text{Maximum bending moment } (M_{max}) = \frac{W_l L}{8} \quad (1)$$

With an external weight (Wl) of 100 kg per member and a length (L) of 0.4 m, the maximum bending moment is 4.91 Nm. Using equation 2 below, this will give a sectional modulus of 0.316cm3.

$$\text{Sectional modulus } (z) = \frac{M_{max}}{\sigma_b} \quad (2)$$

Based on this, angle iron (2 × 2 × 1.5 mm) and hollow square pipe (1.5 mm) were selected. This selection will also cater for the bending moment due to the self-weight of the members.

Equation 3 was further used to check for failure due to vertical shear stress of component parts.

$$\text{Vertical shear stress } (\sigma_v) = \frac{W_l}{A} \quad (3)$$

The values of σ_v were found to be lesser than σ_b which implies that the selected section will not fail under vertical stress.

Trailer Wheel

The technical considerations for wheels of a bicycle and motorcycle trailer will depend on the weight to be carried and the conditions of the road. In addition, the trailer wheels must be capable of carrying a load of 100 – 200 kg and must have a low friction bearing in the hubs.

In other to sustain the design load, the rear wheel of a motor cycle was selected for the FPD and CPD trailers for the bicycle and motorcycle. For the two designs, the wheel will have the following specifications; external diameter of 584.2 mm, rim diameter of 431.8 mm, thickness of 7.62 mm and pressure: 36 psi. For WMD bicycle trailer, the wheel selected was a Raleigh bicycle wheel

Shaft for Trailer Wheel

A major requirement for a two wheel bicycle and motorcycle trailer is that the wheels must rotate independently of each other. To achieve this, slotted plates and the rear shaft of a motorcycle wheel were selected for the FPD and CPD trailers for bicycle and motorcycle. The shaft for a Raleigh bicycle wheel was used for the WMD bicycle trailer. The slotted plates allow each wheel to be removed independently for repair and maintenance. These shafts used for the trailers were around 17cm long. The shafts will be subjected to bending moment only. For a round shaft, the diameter is given by equation 4.

$$d = \sqrt[3]{\frac{32M}{\pi\sigma_b}} \quad (4)$$

Where; M is the bending moment due to the load on the shaft (N) and σb is the bending stress (N/m2).Figure 7shows the free body diagram, shear force (Qy) diagram and bending moment (Mx) diagram of the shaft. From figure 7, the total load to be carried by the shaft is a point load of 2.25 kN which comprises the half self-weight of the trailer and the load to be carried by each wheel. This load will give rise to different reactions at the supports. The maximum shear force on the shaft is 2.813 kN (figure 7), while that the maximum bending moment on the shaft is 0.239 kNm.

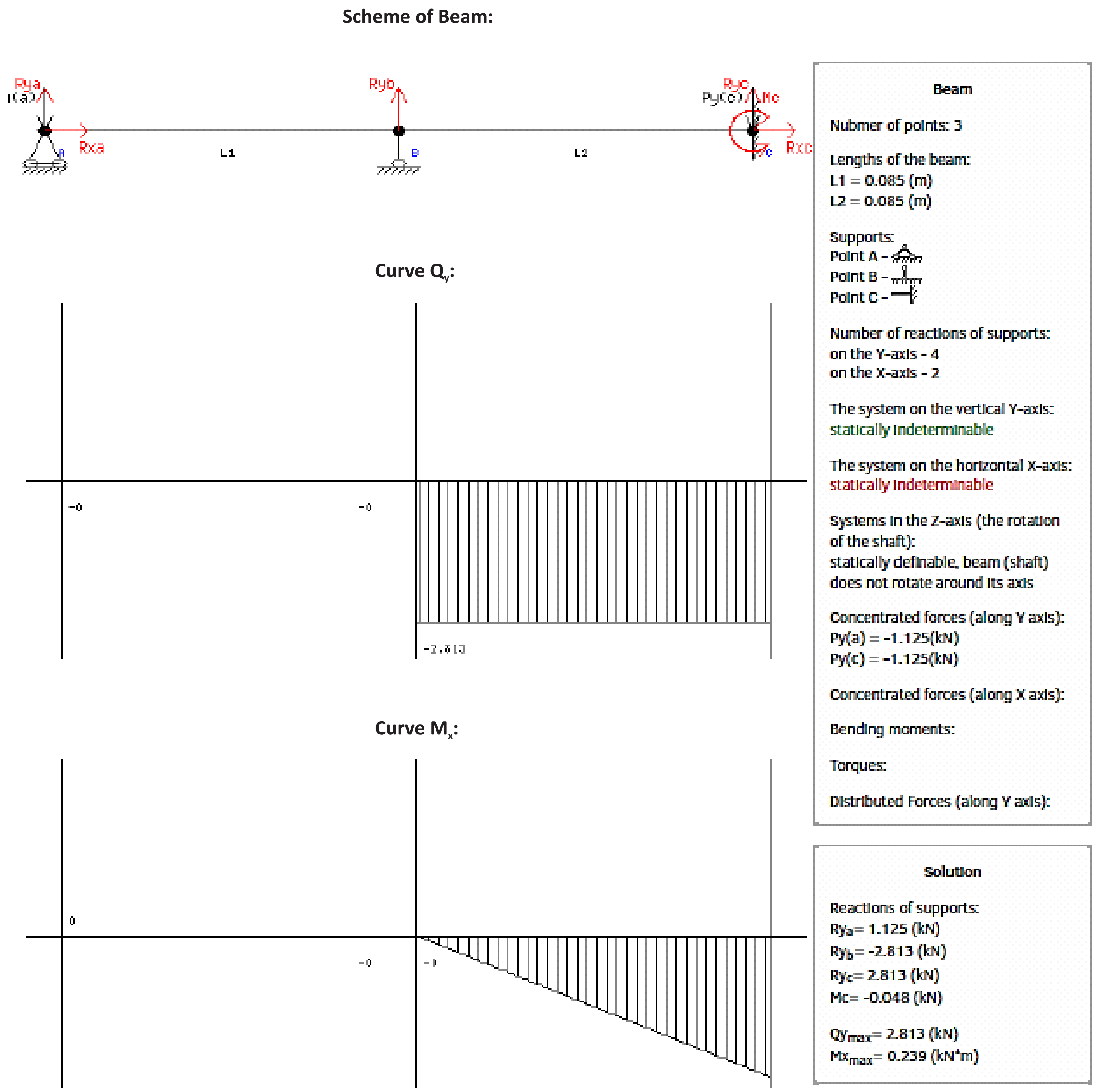

Figure 7: Shaft analysis

Using a bending moment of 0.239 KNm in equation 4, a shaft diameter of 2.5 mm is appropriate.

3.1.5 Hitch System

The hitch system comprises; the hitch (between the trailer and the cycle), the hitch mount (on the bicycle and the motorcycle) and the hitch support frame (attachment to the trailer chassis or plate). The hitch system used for the WMD bicycle trailer was a conventional universal joint and collar attached to the trailer chassis (figure 8). On the other hand, the hitch system for the bicycle and motorcycle FPD and CPD comprises an annular of heavy duty cylindrical cone housing and a bolt (figure 9 and 10).These hitch systems were chosen since they have three degrees of freedom.

Figure 8: Hitching system for bicycle WMD trailer

Figure 9: Hitching system for bicycle FPD and CPD trailers

Figure 10: Hitching system for motorcycle FPD and CPD trailers

Fabrication

Figure 11 summarizes the fabrication processes which are: gathering of materials, fabrication of chassis base, fabrication of chassis wall, covering chassis with metal plates, installation of wheel shaft, installation of wheels, installation of wheel mud guard, installation of hitching point, fabrication and installation of hitch, painting and lastly mounting the trailer to the bicycle and motorcycle. The summary of the components along with the materials used is as presented in Table 1.

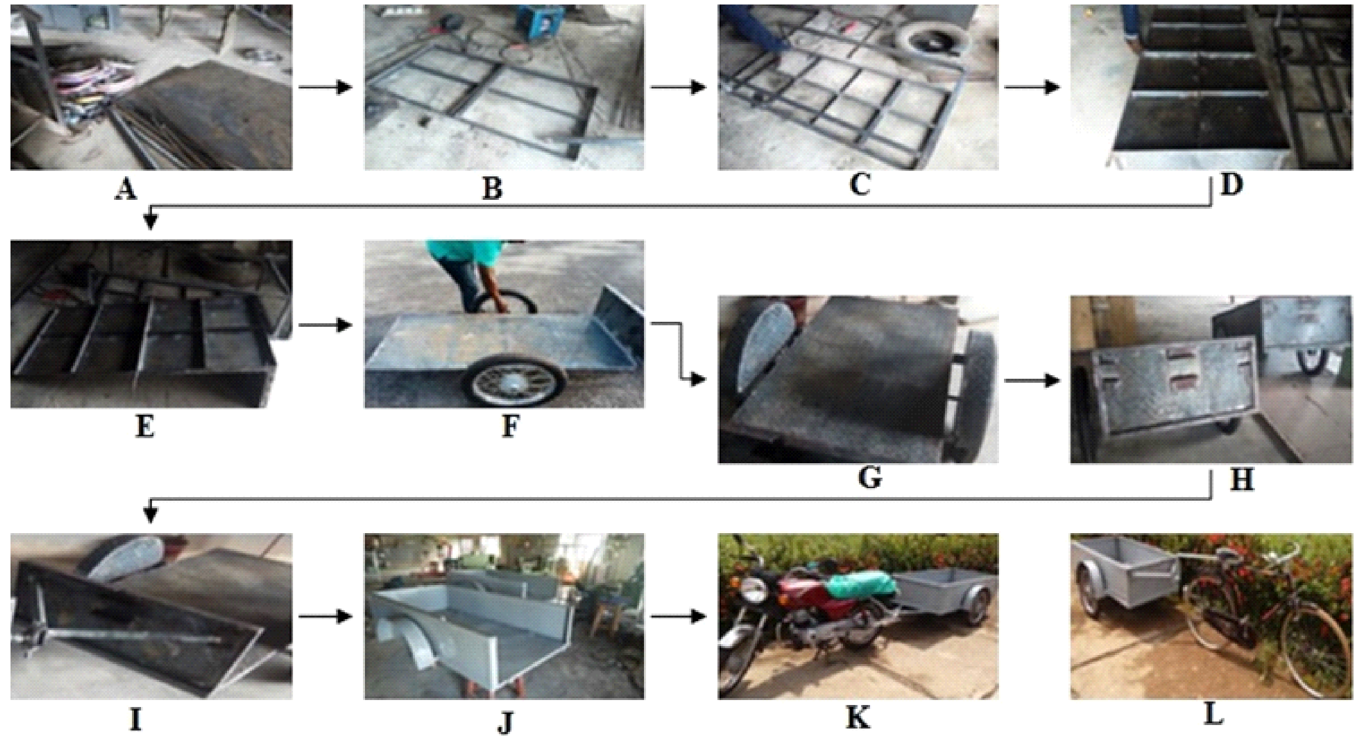

Figure 11: Fabrication process (Key: A – Gathering materials; B & C – Chassis fabrication; D – Fixing plates (or wire mesh); E – Installing Wheel shaft; F – Installing wheels; G – Fixing wheel mud guard; H – Adding hitch point; I – Adding Hitch; J – Painting; & K/L: Mounting on cycles).

Table 1: Components of trailers

S/N	Components	Bicycle Trailer	Motorcycle Trailer
1.	Chassis	Angle iron (2 × 2 × 1.5 mm) and (1.5 × 1.5 × 1.5 mm)	Hollow square pipe (1.5 mm)
2.	Base plate FPD&CPD	Standard chequered mild steel plate (2 mm)	Standard chequered mild steel plate (2 mm)
	Base plate WMD	Wire mesh and plywood	N/A
3.	Side plate WMD	Wire mesh	N/A
	Side plate FPD	Standard chequered mild steel plate (2 mm)	Standard chequered mild steel plate (2 mm)
	Side plate CPD	Aluminium plate (1.5 mm)	Aluminium plate (1.5 mm)
4.	Shaft	Motorcycle rear shaft	Motorcycle rear shaft
5.	Wheel FPD&CPD	Motorcycle rear wheel	Motorcycle rear wheel
	Wheel WMD	Raleigh bicycle wheel	N/A
6.	Hitch point on trailer	Two hitch point at the front side of the trailer	Welded to the chassis of the trailer
7.	Hitch support frame	Hollow mild steel pipe (25 × 25 × 2.6 mm)	Hollow mild steel pipe (25 × 25 × 2.6 mm)
8.	Hitch	Mild steel stock (Universal joint), mild steel strip, nut(s) and bolt(s)	Hardened steel cylinder mated with a heavy duty bolt
9.	Hitch point on cycle	Bolted beneath the seat	Attached to the rear wheel
10.	Paint	Ash colour gloss (auto-base paint)	Ash colour gloss (auto-base paint)

Key: FPD – Fixed plate design; CPD – Convertible plate design and WMD – Wire mesh design

Performance Evaluation

A computer based simulation was carried out on the model of the trailer chassis using ANSYS 14.5. This was used in identifying the equivalent stress and strain when subjected to the following conditions.

1. Maximum load
2. A frictionless support
3. Acceleration due to gravity

In addition to this, preliminary field tests were carried out. This test was aimed at investigating the stability and turning ability of the entire design; the comfort ability of the operator and the ease of dissembling the hitch. The speed of the cycles was also observed for a distance of 250 m. the motorcycle was at its lowest gear during this evaluation.

Results and Discussions

Figure 12: WMD bicycle trailer in use

Figure 13: CPD motorcycle trailer

Figure 14: CPD bicycle trailer

Figure 15: FPD motorcycle trailer in use

Figure 16: Un-mounted CPD bicycle trailer showing two hitching points

Figure 17: Un-mounted CPD bicycle trailer (collapsed) showing two hitching points

Figure 18: Un-mounted CPD motorcycle trailer (collapsed) showing the hitching point

Static Structural Analysis of Trailer Chassis

Figure 19 and 20 shows the result of the static structural analysis of the trailer chassis. Figure 16 shows that a maximum stress of 2.95 × 106 Pa occurred at the joints; while figure 17 reveals the different strains on the member. The maximum strain was observed to be 8.22 × 10-6mm

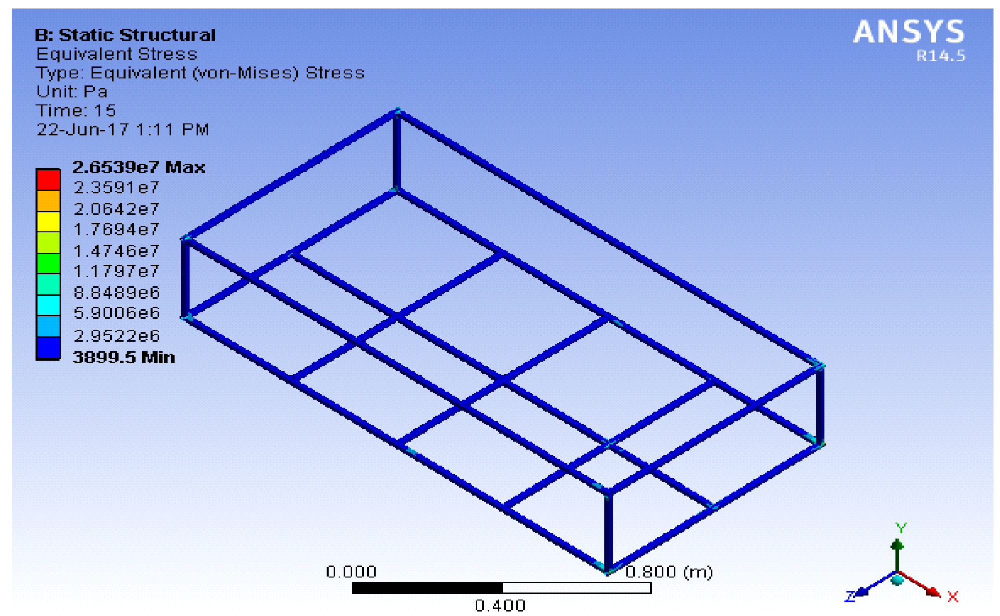

Figure 19: Equivalent stress of trailer chassis

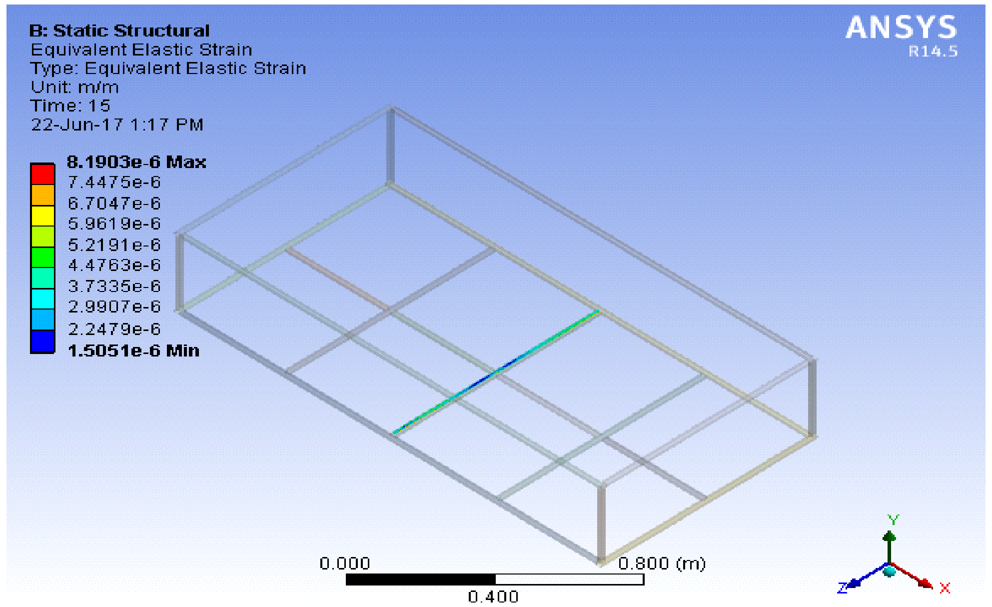

Figure 20: Equivalent strain of trailer chassis

Challenges

The major challenge encountered was developing a simple and workable hitching system. The initial design proposed a single point hitch system which was fabricated (figure 21a).This design had poor turning ability and stability. A readjustment (figure 21b) was done for the bicycle trailer; by changing the hitch point on the trailer to two (for good stability) and linking this two hictch to another hitch (for a better turning ability) while for the motorcycle trailer; the hitch support frame was welded to the base of the chassis.In addition, it was discovered that the trailer fabricated for the bicycle was heavy. So a new trailer (light weight) was designed and fabricated (figure21c) and subsequently their performance evaluated

Figure 21: Readjustment of hitching system

Preliminary Evaluation

Preliminary evaluation have shown satisfactory performance based on the load carrying capacity; stability of the trailer, bicycle and motorcycle; turning ability; comfort of the operator and ease of disassembling the hitch. Overturning was not observed all through. Figures 22 and 23 shows the average speed of the trailers when mounted on a motorcycle and bicycle, respectively. At no load, the motorcycle trailer had a stable speed of 8 – 10 km/hr and 7 – 8.5 km/hr at full load. The no load speed of the bicycle trailer was less than 6 km/hr while at 100 kg load, the speed was less than 5 km/hr. From figure 24, the WMD bicycle trailer attained a higher and a more stable speed of (5.2 – 6.3 km/hr at no load and 4.9 – 5.6 km/hr at 100 kg) compared to the FPD/CPD bicycle trailers (5.0 – 5.4 km/hr at no load and 3.8 – 4.2 km/hr at 100 kg). This was specifically due to the light weight of the WMD bicycle trailer.

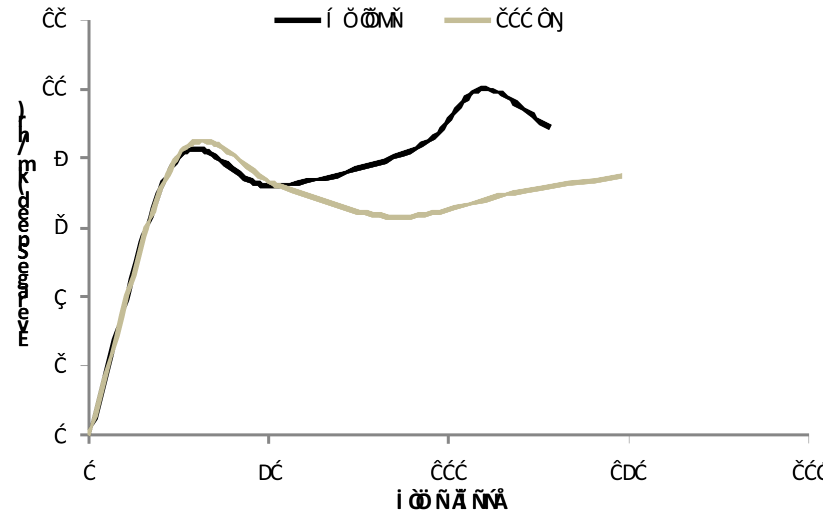

Figure 22: Average speed of FPD/CPD motorcycle trailer

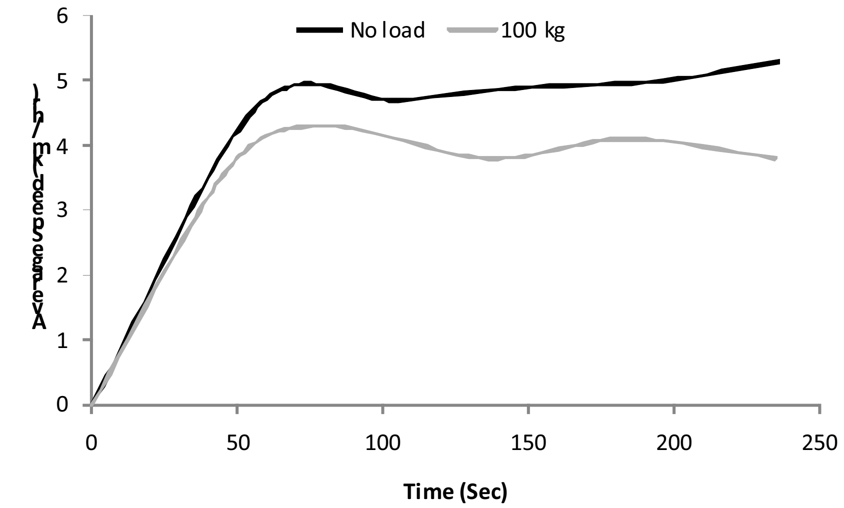

Figure 23: Average speed of FPD/CPD bicycle trailer

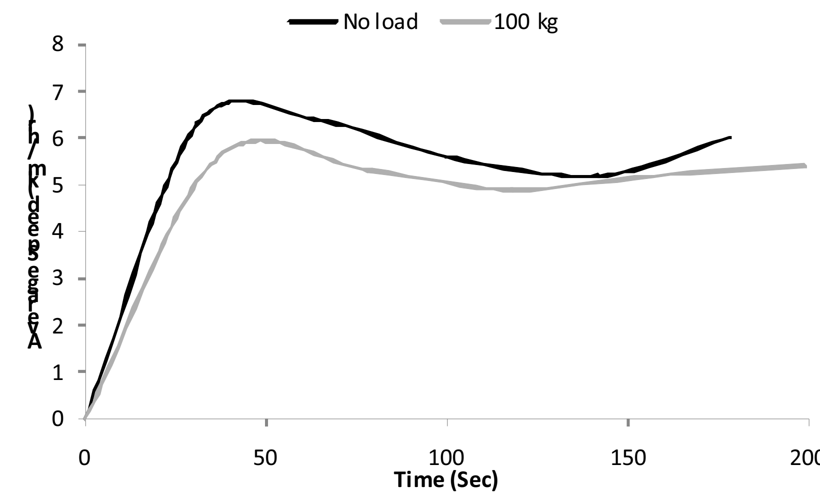

Figure 24: Average speed of WMD bicycle trailer

Conclusion

This study has helped in safely increasing the load carrying capacity of humans (from 10-20 kg to 200 kg) on long distances; safely increasing the load carrying capacity of bicycles; ease of detaching hitch; simple hitch system; convertible trailer; carrying large loads without polluting the environment (in the case of bicycle trailers); reduced drudgery; enhanced/proper material handling; reducing percentage of material damaged during transit; etc. There is no doubt that a proper usage of the trailers presented in this study will boost the health and wealth of farmers and other rural dwellers.

Acknowledgments

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