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Evaluation of Rural Transportation Technology: A Case Study of Bicycle and Motorcycle Trailers

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ABSTRACT

Transportation of goods in rural communities, especially from farms, is one of the major bottlenecks experienced by rural dwellers. Bicycle and motorcycle trailers have been a major intervention proposed by several studies but, this technology has not been fully adopted and it has no detailed evaluation report. This study, therefore, evaluates the performance of different bicycle and motorcycle trailer designs. Three different designs of bicycle trailers (fixed plate design (FPD), convertible plate design (CPD) and wire mesh design (WMD)) and two designs of motorcycle trailers (FPD and CPD) were developed. Four performance evaluation tests (laden mass, forward speed, pull and haulage tests and a computer-based simulation of stress/strain analysis) were carried out. The optimum load capacity (OLC) of WMD bicycle trailer is 100 kg at a speed of 5.2 – 6.3 km/hr, while that of FPD and CPD bicycle trailers are 100 kg at a speed of 3.8 - 4.2 km/hr. The OLC for the FPD and CPD motorcycle trailer was 200 kg at a speed of 6.2 – 8.4 km/hr. Static structural analysis of the trailer chassis shows that the maximum stress and strain of the trailers were 2.95 × 10^6 Pa and 8.22 × 10^{-6} mm, respectively. This study shows the suitability of the bicycle and motorcycle trailers in small-scale goods conveyance and its suitability for the rural community.

Keywords: Bicycle; Drawbar; Haulage; Laden Mass; Motorcycle; Trailers

INTRODUCTION

Effective transportation is a crucial factor affecting the development of many nations; hence, a workable mode of transportation is essential. The need to respond to the transportation problems in rural communities and the challenges of high transportation cost shows the need to integrate non-motorised transportation (NMT) into existing modes of transportation. In addition, an effective and a well-planned NMT system will have a good influence on the vehicle used in a society thereby reducing road traffic congestion, air and noise pollutions, auto-crashes, vibrations, etc. (Dawood & Rahmat 2015; Ismail & Zakaria 2014) which is in support of the sustainable development goals of the United Nations. NMT is any form of transportation that is used in conveying of goods by other methods asides the use of combustion motors. Examples of NMT include; walking (the simplest form of NMT), bicycles, handcarts, tricycles, animal-driven cart, etc. Early in the last century, bicycles were the major transportation means for daily trips, but when the need to speed up movement arose, motor vehicles and motorcycles became the popular choice. The economic situation in recent years has made the use of motor vehicles to overshadow NMT as a major transportation means. This trend, however, is predominant in urban areas, while NMTs (especially walking, bicycles and motorcycles) are still the major means of transportation in the rural communities.

Meagre transportation facilities in the rural areas of low-income countries limit economic and social development leading to poverty. This transportation system can be improved through better transport infrastructure, efficient transport services, and consideration of the location, quality, and price of transport facilities (Starkey et al. 2002). Good transport services have a critical influence on the reduction of poverty and encouraging economic growth in rural areas (Porter 2014).

In many developing countries, local roads, tracks, footpaths, bridges and other transportation infrastructure used to access farms, markets, schools, clinics, etc. are often in a deplorable condition. In addition, transport services, trucks, buses, pickups, cars and NMTs are often insufficient and usually do not reflect the transport requirements (Sieber 1999). A survey of slum residents in Nairobi, Kenya by Salon and Gulyani (2009) revealed that the majority cannot afford motorized transport options. In many rural communities in most of Sub-Sahara Africa, village transport still involves people walking and carrying (Starkey 2002; Starkey et al. 2002; Starkey & Hine 2014). These people are majorly women (Porter 2002) who carry loads of around 50 kg per day for over four hours (Philpott 1994) which is dangerous to their health (Porter et al. 2007). In addition, Bryceson et al. (2003) observed that livelihood work was the most frequent purpose of short-distance travel in rural areas in Uganda and Zimbabwe. Since farming is one of the major livelihood works in rural communities, NMT will be a major solution to their transportation problems.

In many Asian countries where non-motorised bicycles (two-wheelers) and three-wheelers are in use, there are special adaptations to the vehicles for goods transport, hawking or taking passengers. Bicycle trailers were developed within Practical Action South Asia (Sri Lanka); later adopted in Kenya, Nepal and Zimbabwe (Michael 1986). Bicycle trailers are used in many world regions to broaden the transportation modes (Dorsey 2008). It is used for transporting goods, fuel, water, and harvest where other means are expensive. Trailers allow people to carry three times as much as with a bicycle, up to 200 kg (Michael, 1986). Adeoti (1990) reported the load capacity of bicycle and motorcycle trailers to be; 100-120 kg and 100-250 kg, respectively.

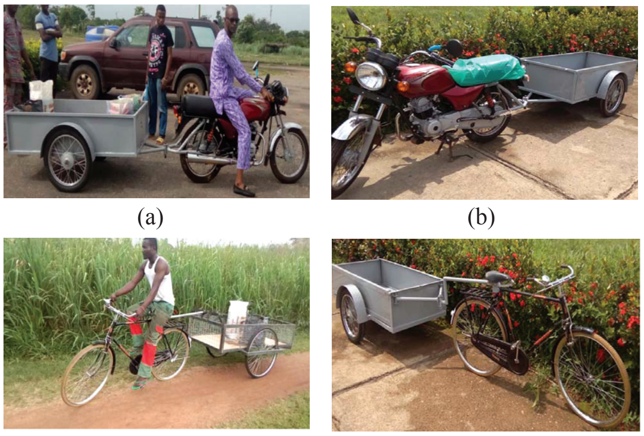
Michael (1986) reported two different designs for bicycle trailer namely a frame design made from the tubular and angle bar. The trailer was hitched to the bicycle above the rear wheel (under the seat). The bicycle trailer developed has been used for mobile store and kitchen, and mobile library for school children in Sri Lanka. Mohammed (1997) reported the cycle trailers in Ghana as a reasonable but inappropriate technology due to the limitation in carrying capacity and cost. Khan et al. (2017) reported the development of a bicycle trolley (trailer). The trailer was mounted on the rear axle of a bicycle. The hitch comprised a rubber coupling which rotates about a single axis. A 16-inch wire spoke wheel was used for the trailer. The base frame of this trailer was attached to the wheels with the help of a slotted-plate type of arrangement. Although Khan et al. (2017) did not state the performance of this trailer; but reported the carrying capacity of this trailer has 120 kg. Other trailer designs and applications available in the literature were examined by Ayre (1986), Hastings et al. (2016), and Wallrapp and Faust (2008).

There has been an insufficient investigation into the performance of bicycle and motorcycle trailers despite the diverse designs available. This gap can be due to the little or no standard test procedure available; making it difficult to evaluate, compare and rank bicycle and motorcycle trailers. The only means of comparing trailers is the loading capacity which is not only partly inconsequential but also insufficient. One of the few standard test procedures of carriage technologies readily available is BIS (1988) for an animal-powered cart which was adopted by Karale et al. (2016). This study, therefore, presents the performance evaluation of different bicycle and motorcycle trailers by adapting the test procedure reported in BIS (1988). It presents the procedure and result of the field, drawbar and haulage tests which can be adapted to evaluate and compare other trailers.

METHODOLOGY

DESCRIPTION OF BICYCLE AND MOTORCYCLE TRAILERS

Three different trailers have been developed for the bicycles, while two trailers were developed for the motorcycles. A fixed plate design (FPD), convertible plate design (CPD) and wire mesh design (WMD) were developed for the bicycles, while the fixed plate design (FPD) and the convertible plate design (CPD) were developed for the motorcycle trailers (see Figures 1a-d). These 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 the load of 100-200 kg on earthen and bitumen roads. Some of the variables used in the design include bicycle wheel diameter – 0.74 m; motorcycle front wheel diameter – 0.57 m; motorcycle rear wheel diameter – 0.58 m; bending stress of mild steel – 155 × 10^6 N/m^2; shear stress of mild steel – 40 × 10^6 N/m^2.



(a) (b) (c) (d)

FIGURE 1. (a) FPD motorcycle trailer in use, (b) CPD motorcycle trailer, (c) WMD bicycle trailer in use and (d) CPD bicycle trailer

TRAILER CHASSIS 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 a maximum load, frictionless support and acceleration due to gravity.

PERFORMANCE EVALUATION

Field tests were carried out to investigate the stability and turning ability of the entire cycle trailer assembly; the comfortability of the operator and the ease of dissembling the hitch. The speed was also observed for a distance of 250 m. The motorcycle was at its lowest gear during this evaluation. Haulage test was conducted by adopting the methodology reported in BIS (1988) and Karale et al. (2016) by hauling 50 kg load on bitumen and earthen road. The test was conducted for each of the trailers. Drawbar test was also conducted by adopting the methodology reported in BIS (1988) and Karale et al. (2016). In this test, the pull corresponding to the laden mass of carriage and forward/moving speed were measured.

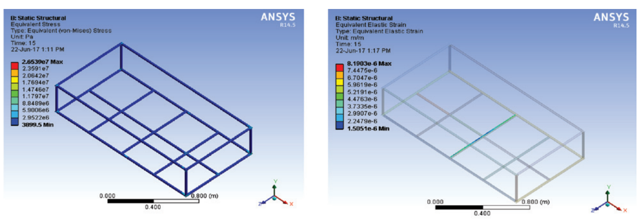
These tests were initially carried out when the trailers were empty and later when loaded in steps of 50 kg until the optimum load capacity (OLC) was reached. Five trials of the test were conducted for each trailer carrying a particular amount of load on bitumen and earthen roads of 50 m length. The track was level and without gradient.

The measurements taken during these tests include; the maximum speed (km/h) attained by the trailers, the moving average speed (km/hr), the overall average speed (km/h) and the time taken (sec). These measurements were taken using Garmin etrex® 10 navigator (under the trip computer option) which was held by the motorcycle/bicycle rider. The trip computer data was set to zero before each 50 m trip commenced.

RESULTS AND DISCUSSION

STATIC STRUCTURAL ANALYSIS OF TRAILER CHASSIS

Figures 2a and 2b show the result of the static structural analysis of the trailer chassis. Figure 2a shows that a maximum stress of 2.95×10^6 Pa occurred at the joints; while Figure 2b reveals the different strains on the member. The maximum strain was observed to be 8.22×10^{-6} mm.



(a) (b)

FIGURE 2. (a) Equivalent stress of trailer chassis and (b) Equivalent strain of trailer chassis

FIELD PERFORMANCE

Performance evaluation on the field has shown satisfactory results based on the load carrying capacity, stability of the trailer, bicycle, and motorcycle, turning ability, the comfort of the operator and ease of disassembling the hitch. Overturning was not observed all through this study. Figures 3 and 4 show the average speed of the trailer when mounted on the motorcycle and bicycle, respectively. At no load, the motorcycle trailer has a speed of 8 – 10 km/hr and 6.2 – 8.4 km/hr at full load. The speed of the FPD and CPD bicycle trailers at no load and 100 kg load was less than 4.6 – 5.3 and 3.8 – 4.3 km/hr, respectively. From Figure 5, 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 and CPD bicycle trailers. This was specifically due to the light weight of the WMD bicycle trailer.

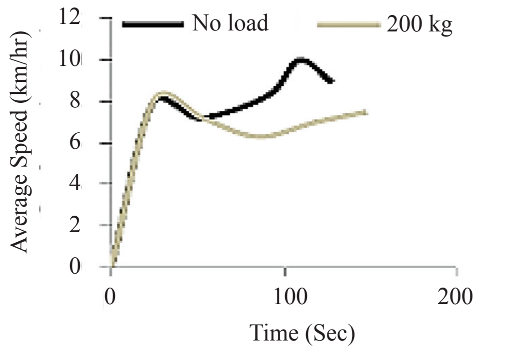


FIGURE 3. Average speed of FPD/CPD motorcycle trailer

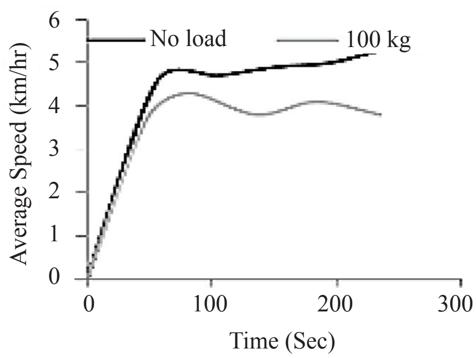


FIGURE 4. Average speed of FPD/CPD bicycle trailer

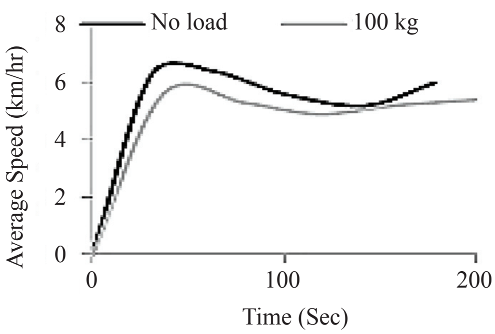


FIGURE 5. Average speed of WMD bicycle trailer

LADEN MASS, FORWARD SPEED, AND PULL

Figures 6 – 10 show the relationship between the laden mass of the trailers and the pull on bitumen and earthen roads. For all the trailers, linear relationships exist between the laden mass and the pull. A greater amount of pull was required on earthen roads for each of the trailers as a result of a higher coefficient of rolling friction between the trailer's tyres and the road.

Figures 11-15 show the relationship between the forward speed and the pull for WMD bicycle trailer on bitumen road, WMD bicycle trailer on earthen road, FPD/CPD bicycle trailer on bitumen road, FPD/CPD bicycle trailer on earthen road and FPD/CPD motorcycle trailer on bitumen road, respectively. Similar to the observations of Karale et al. (2016) on bullock pulled carts, there was a drop in forward speed of most of

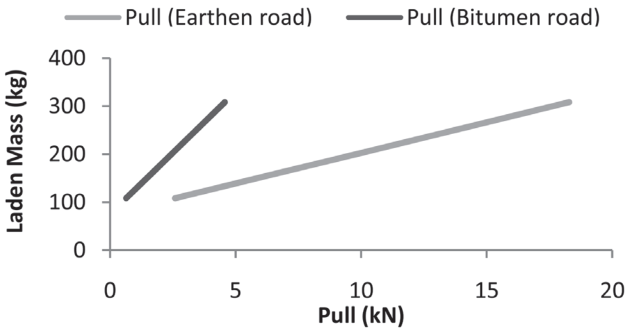


FIGURE 6. Laden mass of WMD bicycle trailer

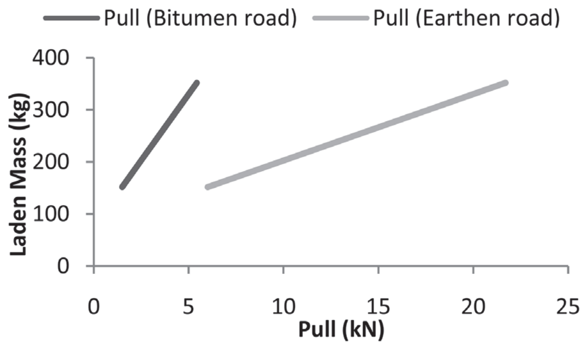


FIGURE 7. Laden mass of FPD bicycle trailer

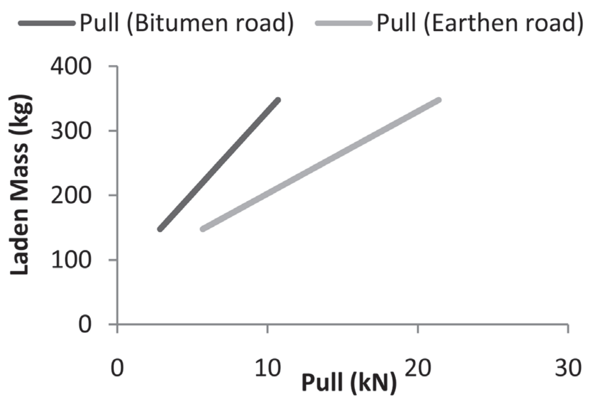


FIGURE 8. Laden mass of CPD bicycle trailer

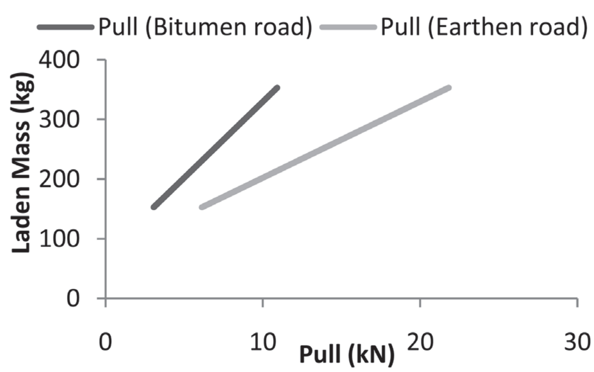


FIGURE 9. Laden mass of FPD motorcycle trailer

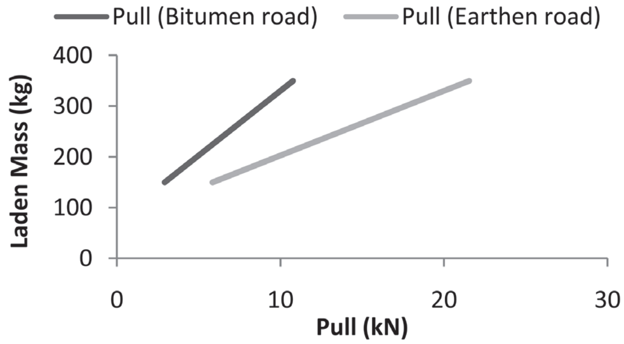


FIGURE 10. Laden mass of CPD motorcycle trailer

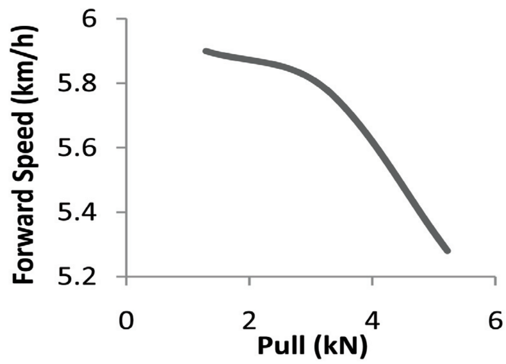


FIGURE 11. Forward speed of WMD bicycle trailer on a bitumen road

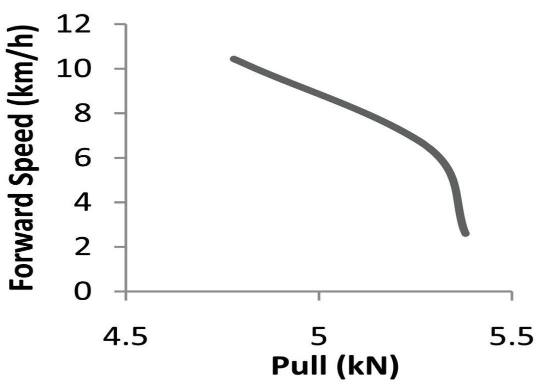


FIGURE 12. Forward speed of WMD bicycle trailer on the earthen road

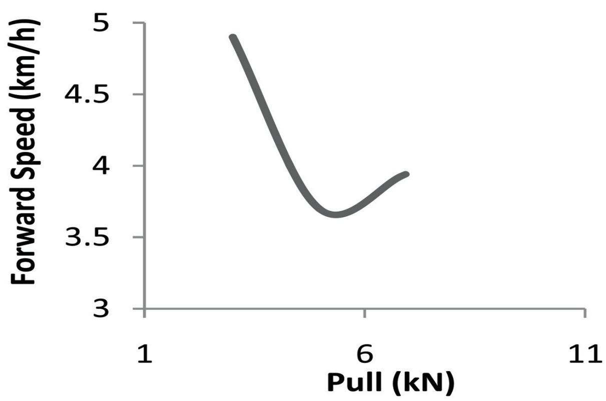


FIGURE 13. Forward speed of FPD/CPD bicycle trailer on a bitumen road

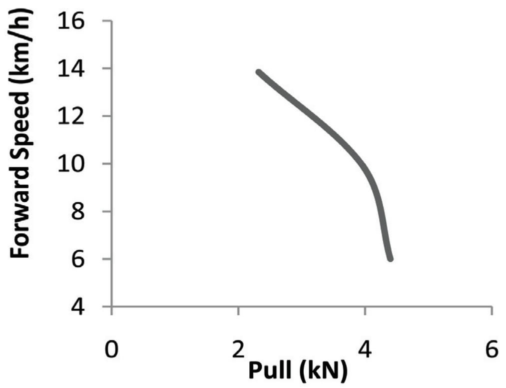


FIGURE 14. Forward speed of FPD/CPD bicycle trailer on earthen road at different pulls

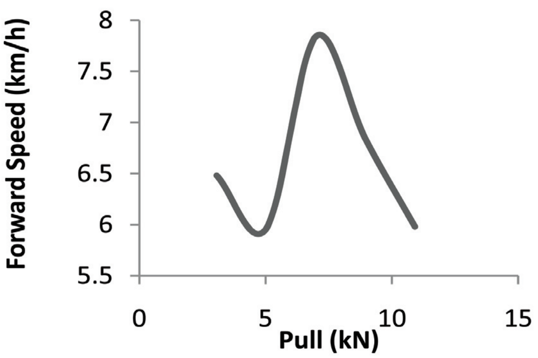


FIGURE 15. Forward speed of FPD/CPD motorcycle trailer on bitumen road at different pulls

the trailers as the force required to pull the trailers increased as a result of an increase in the amount of load. The FPD/CPD motorcycle trailer on bitumen road and the FPD/CPD bicycle trailer on bitumen road showed a slight deviation from this observed trend because as the load was increased, there was increased stability leading to better comfort for the rider which led to an increase in forward speed. The forward speed of these trailers was observed to be higher than that of all the bullock carts reported by Patre et al. (2018). Generally, there was a restriction in the OLC of the three bicycle trailers. These trailers could not be loaded beyond 100 kg; not because the trailers could not carry them. This restriction became necessary so as to avoid discomfort and undue stress on the riders.

HAULAGE OF THE TRAILERS

Tables 1 and 2 show the result of the haulage test carried out for the trailers on bitumen and earthen roads, respectively. It shows an overall satisfactory performance of the trailers. The turning ability of the motorcycle trailers was slightly uneasy because of the slight restriction placed on the rear wheels by the hitch system and an unevenly distributed load on the trailers. This turning ability became better with an increase in the amount of load. This is better than the report of Nair et al. (2018) in which steering was affected because the cart was positioned in front of the cycle.

The stability of FPD and CPD bicycle trailers was observed to be affected by the amount of load and also the type of road. This was also observed by Khan et al. (2017). This slight instability (especially when the load is not evenly distributed on the trailer bed) led to the slight discomfort experienced by the rider. The instability and the discomfort were observed to be reduced when the load was well distributed.

FACTORS AFFECTING THE PERFORMANCE OF BICYCLE AND MOTORCYCLE TRAILERS

Certain factors were observed to affect the performance of the trailers some of which include; the amount of load, road type, and trailer design.

TABLE 1. Performance result of trailers' haulage test on a bitumen road

Haulage parameters	FPD bicycle trailer	CPD bicycle trailer	WMD bicycle trailer	FPD motorcycle trailer	CPD motorcycle trailer	Remarks
Duration, min	30	30	30	30	30	-
Trailer laden mass, kg	201.5	197.5	158	203	197.5	-
Operator weight, kg	75	75	75	75	75	-
Travel speed, km/h	N/A	3.7	5.78	5.96	N/A	Speed of motorcycle is limited by instability
Turning ability	Easy	Easy	Easy	Slightly uneasy	Slightly uneasy	Depends on hitch
Stability of trailer	Stable	Stable	Stable	Stable	Stable	Affected by speed and load distribution
Stability of cycle	Slightly unstable	Slightly unstable	Stable	Stable	Stable	Highly dependent on the riding experience of the rider
Comport to operator	Slight discomfort	Slight discomfort	Comfortable	Comfortable	Comfortable	Affected by the amount of load

TABLE 2. Performance result of trailers' haulage test on the earthen road

Haulage parameters	FPD bicycle trailer	CPD bicycle trailer	WMD bicycle trailer	FPD motorcycle trailer	CPD motorcycle trailer	Remarks
Duration, min	30	30	30	30	30	-
Trailer laden mass, kg	201.5	197.5	158	203	197.5	-
Operator weight, kg	75	75	75	75	75	-
Travel speed, km/h	3.96	N/A	5.28	N/A	N/A	Speed limited by the need to ensure stability
Turning ability	Easy	Easy	Easy	Slightly uneasy	Slightly uneasy	Depends on the hitch
Stability of trailer	Slightly unstable	Slightly unstable	Stable	Stable	Stable	Affected by speed and load distribution
Stability of cycle	Slightly unstable	Slightly unstable	Slightly unstable	Stable	Stable	Highly dependent on the riding experience of the rider
Comport to operator	Slight discomfort	Slight discomfort	Slight discomfort	Comfortable	Comfortable	Affected by the amount of load

LOAD

ANOVA of the maximum speed, moving average speed, overall average speed, and the time taken to cover 50 m; of the trailers with different amounts of load revealed that at 5% level of significance, the amounts of load carried affected the maximum speed of all the trailers considered except for the FPD motorcycle trailer (Table 3). The amount of load also had an effect on the moving average speed of all the trailers. Similar to the effect on the maximum speed, the amount of load influenced the overall average speed of the trailers except for the FPD motorcycle trailer. The amount of load also influenced the time taken for FPD bicycle trailer and WMD motorcycle trailer to cover 50 m. This result shows that the loading had no influence on most of the variables measured for FPD motorcycle trailers. This could be attributed to the relatively high weight (78 kg) of this trailer, making the effect of a slight change in weight (as a result of the load added) to be insignificant.

TABLE 3. P-values from the ANOVA carried out on some performance parameters of the trailers with different amount of load

Parameters	FPD bicycle trailer	CPD bicycle trailer	WMD bicycle trailer	FPD motorcycle trailer
Maximum speed	0.003	0.016	0.002	0.094
Moving Average Speed	0.005	0.002	0.041	0.006
Overall average speed	0.001	0.000	0.000	0.644
Time	0.040	0.154	0.013	0.051

ROAD TYPE

Table 4 shows that the average pull of all the trailers on earthen road was higher than that of bitumen. The t-test carried out between the pulls of the trailers on different roads further revealed that at 5% significance, the type of road had an effect on the pulls of WMD and FPD bicycle trailers. These trailers were the lightest (33 and 72.5, kg respectively); hence, the effect of the coefficient of rolling friction on their pulls was significant.

TABLE 4. Result of t-test (paired sample) between the pulls of the trailers on different roads

Trailers	Average Pull on Bitumen Road (kN)	Average Pull on Earthen Road (kN)
WMD bicycle	$2.61\pm1.55_a$	$10.44\pm6.20_b$
FPD Motorcycle	$6.98\pm3.10_a$	$13.97\pm6.20_a$
FPD bicycle	$3.46\pm1.55_a$	$13.85\pm6.20_b$
CPD Motorcycle	$6.85\pm3.10_a$	$13.69\pm6.20_a$
CPD bicycle	$6.77\pm3.10_a$	$13.54\pm6.20_a$

Note: Values in the same row and sub-table not sharing the same subscript are significantly different at p < 0 .05 in the two-sided test of equality for column means.

TRAILER DESIGN

Statistical analysis using t-test revealed that at 5% level of significance, the type of design influenced the pulls of the trailers (except between FPD and CPD Bicycles). Although a strong correlation existed between the pulls of these trailers, a significant difference was observed between the pulls. The use of wired mesh in the WMD bicycle design clearly influenced the pull compared to CPD and FPD bicycle trailers where plates were used.

CONCLUSION

The performance evaluation of three bicycle trailers and two motorcycle trailers were carried out and the results presented. The result of the static structural analysis of the trailer chassis shows that a maximum stress of 2.95×10^6 Pa occurred at the joints; while the maximum strain was observed to be 8.22×10^{-6} mm. The optimum load capacity of WMD bicycle trailer was 100 kg at a speed in the range of 5.2 – 6.3 km/hr, while the optimal load capacity of FPD and CPD bicycle trailers was 100 kg at a speed less than 5 km/hr. The optimum load capacity of the FPD and CPD motorcycle trailers was 200 kg at a speed in the range of 6.2 – 8.4 km/hr. This was carried out at the lowest motorcycle gear. Amounts of load and the distribution of load affected the speed of the trailers, stability of the cycles and the comfort of the riders. Other factors which affected the trailers include the type of road and the trailer design. This study has shown the capability of different bicycle and motorcycle trailers and their suitability on bitumen and earthen roads.

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