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 × 10⁶ Pa and 8.22 × 10⁶ 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 pollution, 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 besides 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-Saharan Africa, village transport still involves people walking and carrying (Starkey 2002; Starkey et al. 2002; Starkey & Hine 2014). These people are mostly 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.
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® 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 $2.95 \times 10^6$ Pa occurred at the joints; while Figure 2b reveals the different strains on the member. The maximum strain was observed to be $8.22 \times 10^{-6}$ mm.

FIELD PERFORMANCE

Performance evaluation on the field has shown satisfactory results based on the loading 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.

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
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

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

**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
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 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>
<thead>
<tr>
<th>Parameters</th>
<th>FPD bicycle trailer</th>
<th>CPD bicycle trailer</th>
<th>WMD bicycle trailer</th>
<th>FPD motorcycle trailer</th>
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<td>30</td>
<td>30</td>
<td>30</td>
<td>-</td>
</tr>
<tr>
<td>Trailer laden mass, kg</td>
<td>201.5</td>
<td>197.5</td>
<td>158</td>
<td>203</td>
<td>197.5</td>
<td>-</td>
</tr>
<tr>
<td>Operator weight, kg</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>-</td>
</tr>
<tr>
<td>Travel speed, km/h</td>
<td>3.96</td>
<td>N/A</td>
<td>5.28</td>
<td>N/A</td>
<td>N/A</td>
<td>Speed limited by the need to ensure stability</td>
</tr>
<tr>
<td>Turning ability</td>
<td>Easy</td>
<td>Slightly uneasy</td>
<td>Easy</td>
<td>Slightly uneasy</td>
<td>Stable</td>
<td>Depends on the hitch</td>
</tr>
<tr>
<td>Stability of trailer</td>
<td>Slightly unstable</td>
<td>Slightly unstable</td>
<td>Slightly stable</td>
<td>Stable</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Stability of cycle</td>
<td>Slightly unstable</td>
<td>Slightly unstable</td>
<td>Slightly unstable</td>
<td>Stable</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Comport to operator</td>
<td>Slight discomfort</td>
<td>Slight discomfort</td>
<td>Slight discomfort</td>
<td>Comfortable</td>
<td>Comfortable</td>
<td>Affected by the amount of load</td>
</tr>
</tbody>
</table>

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 $2.95 \times 10^6$ Pa occurred at the joints; while the maximum strain was observed to be $8.22 \times 10^{-6}$ 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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