# Transport

## Vehicles for Rural Transport Services in sub Saharan Africa

--Manuscript Draft--

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| **Abstract:** | There is a critical lack of affordable transport services linking villages to markets, healthcare and other facilities in rural areas of sub Saharan Africa which significantly restrains rural development. A key factor is the severe constraint on profitability of services due to the high operating costs of conventional vehicles operating at relatively low speeds on rural roads. This paper argues that there is a need to consider lower speed alternatives based on motorcycles. It shows that motorcycle-based vehicles such as trailers and 3-wheelers can carry loads up to one tonne on rural roads when geared down to an appropriate speed. The operating costs of these vehicles are shown to be around half those of conventional vehicles greatly increasing the potential for setting up profitable transport services. Further development is needed to show that motorcycle-based vehicles can be used safely and profitably to help rural people improve their livelihoods and facilitate rural development. |

 

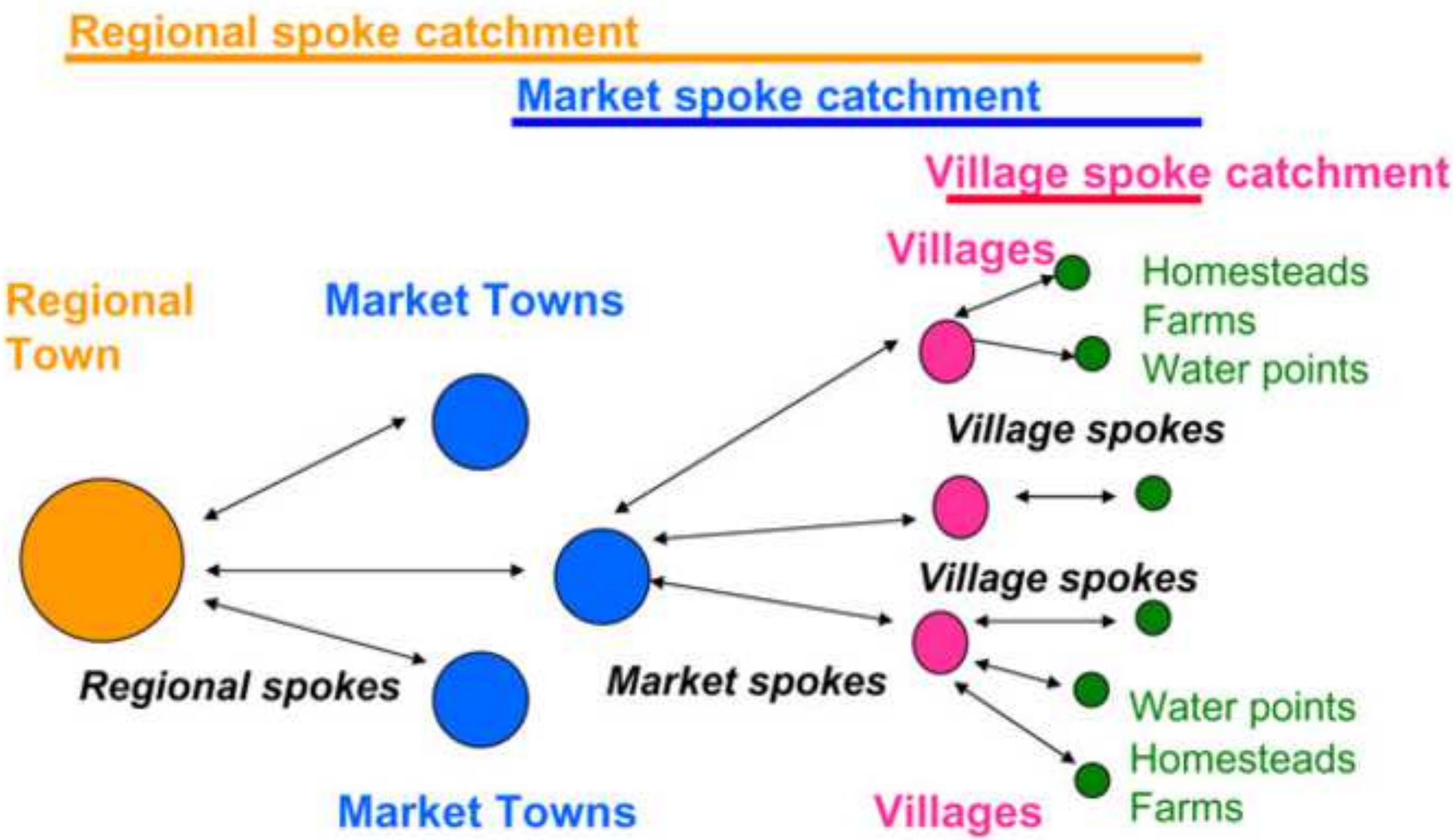
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Figure 2 [Click here to download Figure Fig2.tif](#)

**Figure 2: Typical RTS vehicles**

Figure 3

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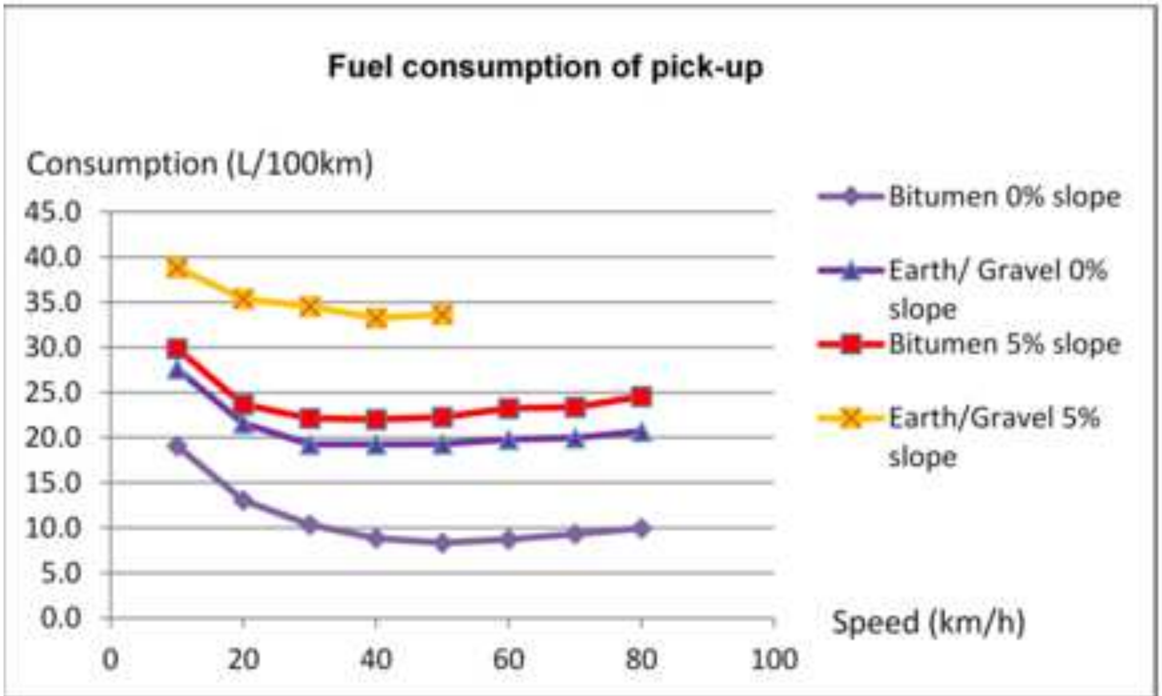


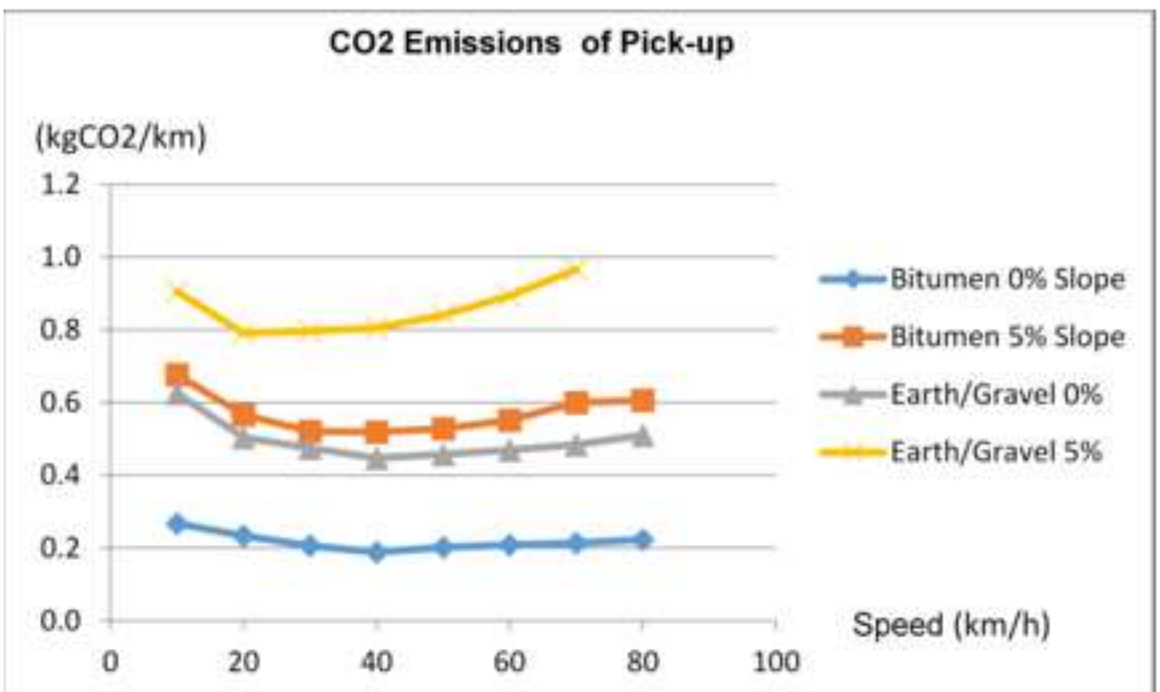

**Figure4: Motorcycle-based vehicles**

Figure 5 Click here to download Figure Fig 5.tif

**Figure 5: Concept of 3-wheeler adaptation of a motorcycle**

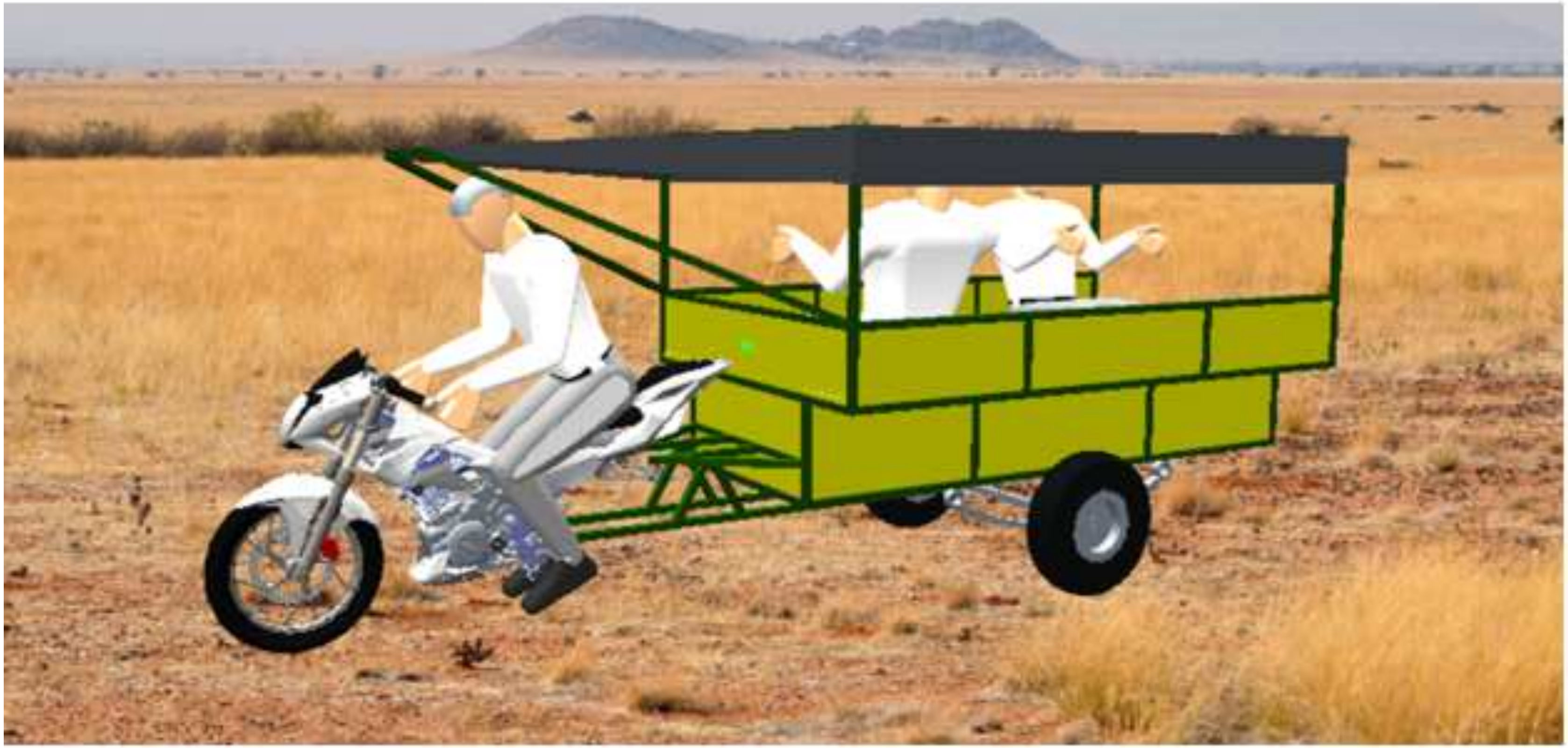

Figure 6 Click here to download Figure Fig 6.tif

**Figure 6: Performance of 250cc MBV on earth/gravel road with 1,000kg load**

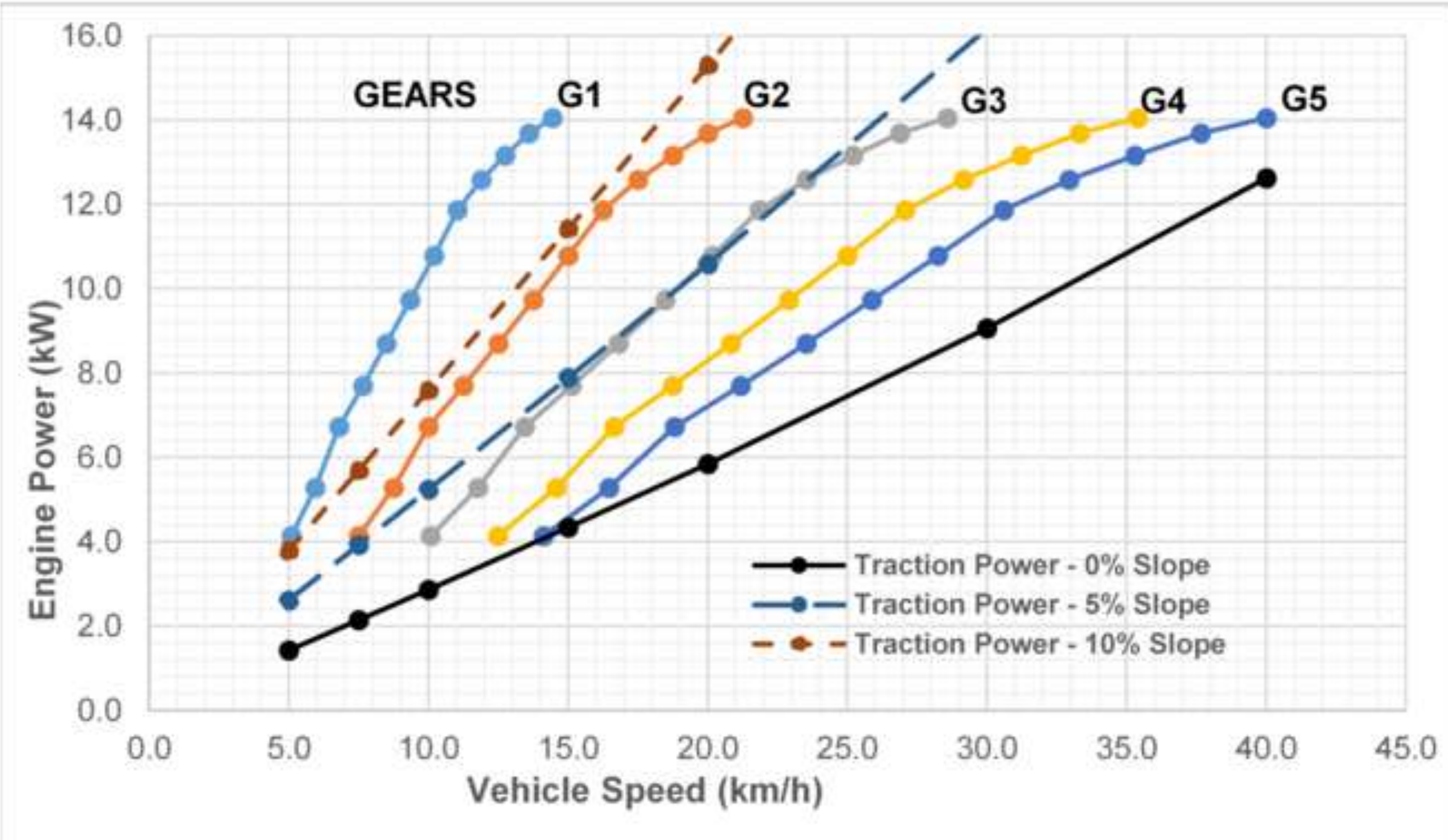

Figure 7 Click here to download Figure Fig 7.tif

**Figure 7: Comparison of fuel consumption of MBV with pick-up**

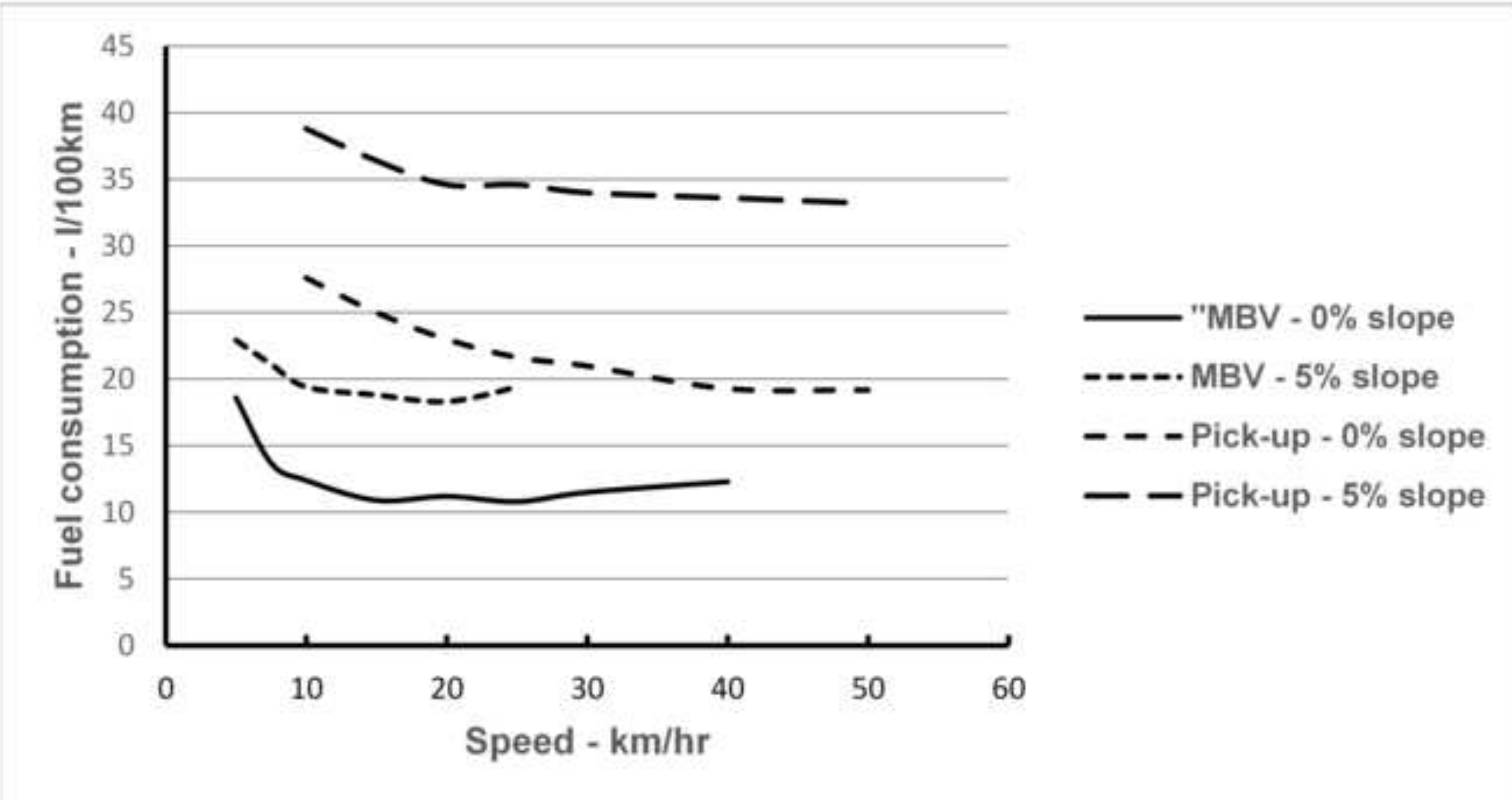

 

**Figure 8: MAT in use in Zambia**

# Vehicles for Rural Transport Services in sub Saharan Africa

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**Abstract**

There is a critical lack of affordable transport services linking villages to markets, healthcare and other facilities in rural areas of sub Saharan Africa which significantly restrains rural development. A key factor is the severe constraint on profitability of services due to the high operating costs of conventional vehicles operating at relatively low speeds on rural roads,. This paper argues that there is a need to consider lower speed alternatives based on motorcycles. It shows that motorcycle-based vehicles such as trailers and 3-wheelers can carry loads up to one tonne on rural roads when geared down to an appropriate speed. The operating costs of these vehicles are shown to be around half those of conventional vehicles greatly increasing the potential for setting up profitable transport services. Further development is needed to show that motorcycle-based vehicles can be used safely and profitably to help rural people improve their livelihoods and facilitate rural development.

**Abbreviations**

| | |
|---|---|
| AFCAP | Africa Community Access Programme |
| DFID | UK government Department for International Development |
| MAT | Motorcycle ambulance-trailer |
| MBV | Motorcycle-based vehicle |
| RTS | Rural Transport Service |
| sSA | sub Saharan Africa |

**Keywords**

Developing countries; Unpaved roads; Transport planning

# 1 Introduction

Around 60% of people in sub Saharan Africa (sSA) including 80% of the poorest live in rural villages (Olinto et al, 2013) and grow subsistence crops on small plots of land to support themselves. Their livelihoods depend largely on selling surplus crops at market and this is the main driver of rural development linked to a growing demand for food that results from increasing urbanisation. However, this is severely constrained by long distances to markets, poor roads and a lack of affordable transport. Since people are generally too poor to own vehicles there is a great need for affordable transport services to provide access to markets, healthcare and other essential services. Unfortunately these are generally lacking. Although there are several complex factors that affect the supply and affordability of rural transport services it is argued in this paper that a key factor is that conventional vehicles designed to operate at high speeds on paved roads operate inefficiently at low speeds on rural earth roads with high fuel consumption and emissions. This creates high operating costs which are a substantial barrier to providing profitable but affordable rural transport services. There is hence a strong case for introducing more appropriate, lower speed vehicles which can be operated profitably to provide the much needed services. This paper reviews this need and proposes a solution based on motorcycle-based vehicles (MBV). Two possible options, trailers and 3-wheelers, are discussed and the successful field trials of a particular example of a motorcycle-based emergency transport service vehicle, a motorcycle ambulance-trailer, carried out by Developing Technologies in Zambia are described.

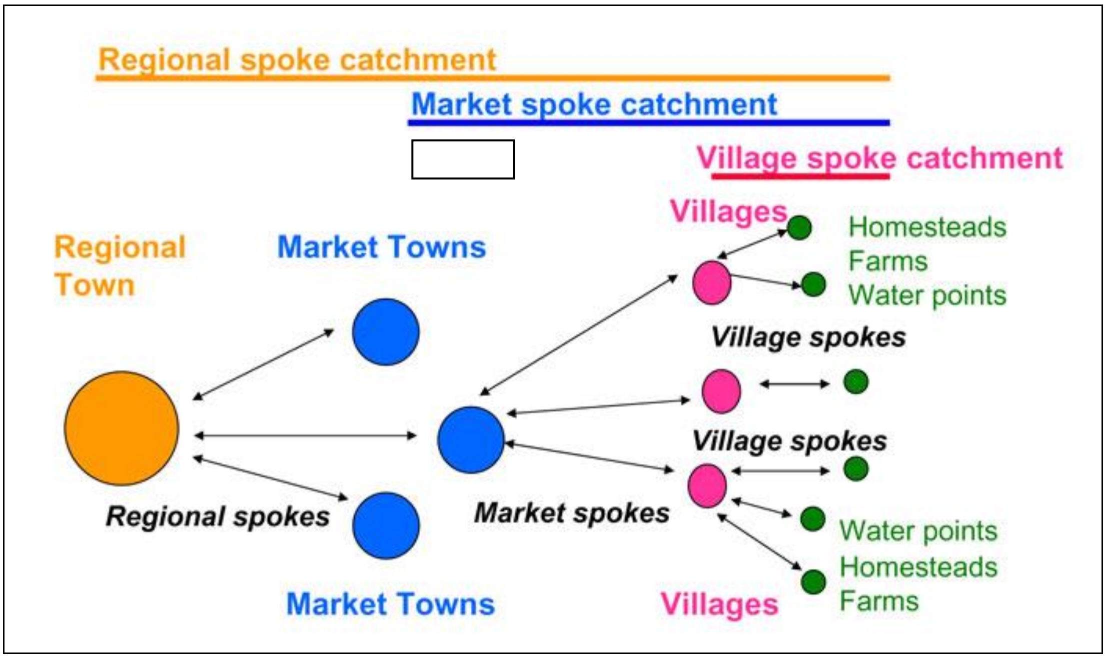
# 2 Rural transport services (RTS) in sSA

Case studies in 4 countries by Starkey *et al* (2007)) found that a general model can be used to describe the pattern of RTS in sSA. This is the ‘hub and spoke’ concept shown in Figure 1 in which the hubs are the main locations between which RTS operate and the spokes are the roads on which they run.

The RTS that exist are generally found at the upper end of the network on trunk roads where there is a concentrated and steady demand that allows RTS operators to make a profit. However, even here there may be considerable delays for users as operators wait to get full loads to achieve that profitability.

The big gap in RTS is usually in the links between villages and markets, health facilities and other resource facilities. This is the most critical area for rural communities providing access to markets and health and other services. The lack of RTS in this area is a key constraint on improving rural livelihoods and rural growth.

**Figure 1: Representation of RTS** (after Starkey et al, 2007)




The role and importance of these village to local resource centre RTS are emphasised in a number of other recent key reviews of rural transport in sSA, including Starkey and Njenge (2010), Banjo (2012), Porter (2013), Starkey et al (2013) and Hine (2014). The authors note that that the main investment, up to 98%, in rural transport has been in infrastucture.There has been a very limited investment in promoting appropriate transport such as bicycles and animal-drawn carts but almost nothing in motorised RTS. It has been generally assumed that once roads were upgraded then RTS would follow automatically as transport operators saw the opportunities provided. However, this has not happened and the reviews show that it is very difficult to make a profit with conventional RTS on village to market routes for a number of reasons:

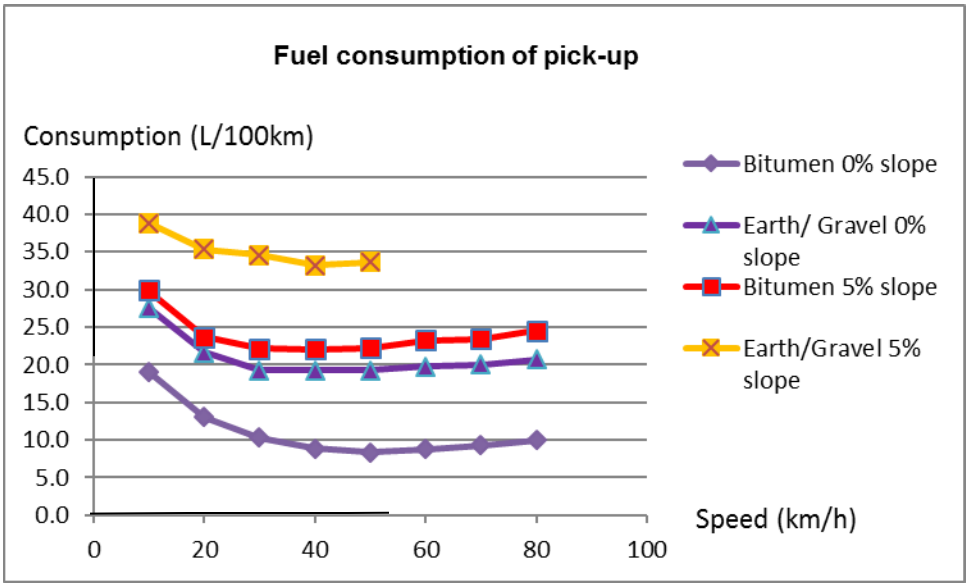
- Demand is dispersed, irregular and seasonal
- Roads tend to be poor and therefore vehicle operating costs are high
- Incomes and therefore affordability are low
- Payloads may be low
- Limited back-up support for vehicle operations

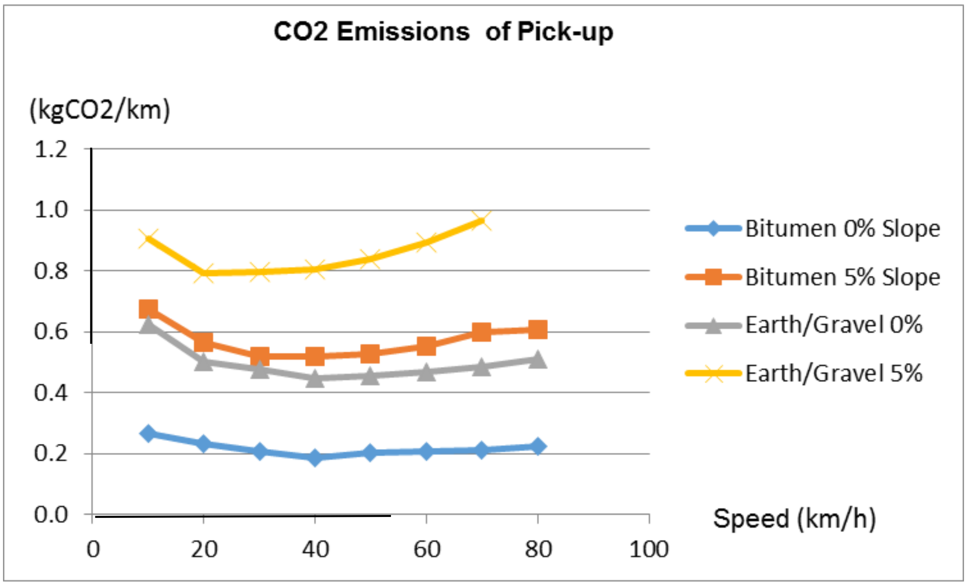
A key factor in this is the high operating costs of conventional vehicles designed for medium to high speeds on bitumen roads when operated on typical rural earth/gravel roads at lower speeds. Typical vehicles used are minibuses and converted pick-ups as shown in Figure 2. The majority of these vehicles are imported as reconditioned vehicles and are probably at least 5 years old when they go into service initially on main hub routes and by the time they filter down to rural routes they will usually be well over 10 years old, Starkey et al (2013).

Using a specific fuel consumption map an estimated comparison of the fuel consumption and $CO_2$ emissions of a typical 2 litre engine used in these vehicles when operating on bitumen and earth/gravel roads is shown in Figure 3. This shows that when operating at an average speed of 50km/hr on earth/gravel roads the fuel consumption and $CO_2$ emissions are about double those at an average speed of 80km/hr on bitumen roads. Since maintenance costs will also be significantly higher on the rougher earth/gravel roads and journey times will be longer, operating costs are likely to be at least 2 times those on bitumen roads. Unfortunately it is very difficult to obtain any reliable data on this, (Starkey et al, 2013), and no specific data is available. Because of the relatively small number of vehicles involved the impact of the higher $CO_2$ emissions is probably negligible but clearly it is an undesirable effect. Increased nitrous oxide emissions are also of concern, particularly where roads pass through villages.

**Figure 2: Typical RTS vehicles**

**Figure 3: Comparison of fuel consumption and $CO_2$ emissions on bitumen and earth/gravel roads**






## 3 Motorcycle-based vehicles (MBV)

It seems clear that to increase the availability of RTS the operating costs of RTS vehicles need to be reduced to make services profitable at affordable fares and therefore vehicles more appropriate to the operating conditions need to be considered. This points to lower power vehicles with a maximum speed of about half of conventional vehicles. Motorcycles are the fastest growing mode of transport in sSA. For example the motorcycle fleet in Tanzania has increased from 31,006 in 2005 to 323,192 in 2010, an annual growth rate of 60% [Hine, 2014]. They have already had a considerable impact on improving the mobility of people in several areas of sSA through the introduction of taxi services where one or two persons are carried on the pillion seat behind the rider. It therefore seems logical to consider the adaptation of motorcycles to transport larger numbers of people and goods.

Motorcycle-based vehicles (MBV) are widely used in some countries in Asia for carrying quite large loads. Figure 4 shows the two possible options, a trailer and 3-wheeler. Motorcycle trailers are common in Cambodia and Vietnam for carrying people and goods whilst 3-wheelers are widely manufactured and used in China. Sperling et al (2005), report that over a million of these vehicles are produced annually and play a major role in rural transport for carrying goods and people.

**Figure4: Motorcycle-based vehicles**

**Motorcycle trailer**

**Motorcycle 3-wheeler**

The majority comprise a small diesel engine and 3-speed gearbox but motorcycle adaptations are also common (Dalkmann et al, 2008). These types of vehicles are viable in China where there is a vast resource of components and spare parts to support their manufacture and operation. The situation in sSA is completely different and for sustainability vehicles need to be based on readily available technologies, for instance adaptations of commonly available motorcycles. Trailers would in fact be the easiest to introduce as they can be readily manufactured in local workshops and used with available motorcycles. However, there is some concern regarding their stability on rural roads when carrying heavy loads, particularly people. 3-wheelers seem intuitively more stable but there have been concerns about overturning in cornering even on smooth surfaces (Challener, Chan and Lock, 2000). This problem will be considerably exaggerated on rough surfaces and there must be some concern about their safety when operating on rural roads. No research on this has been found and it seems highly desirable that stability studies are carried out to prove their safety before they are widely introduced for RTS.

Figure 5 shows an illustration of the concept of a 3-wheeler based on a motorcycle in which the swing-arm and rear wheel of the motorcycle are removed and the bike then attached to a load-carrying chassis with a 2-wheel rear axle. The drive would be by chain from the gearbox via one or more intermediate shafts which would give the required gear reduction to a differential or overrunning clutches on the rear axle.

Figure 6 shows the predicted performance of such a vehicle on earth/gravel roads with a 250cc engine, a maximum speed of 40km/hr and carrying a payload of 1,000kg (equivalent to about 10 people and their goods). It is seen that with the vehicle geared down to reduce the maximum speed to 40km/hr it is able to comfortably transport loads up to 1,000kg on slopes up to 1 in 10 on earth/gravel roads. The average journey speed of around 30km/hr would be quite adequate for transport services linking villages to market/resource centres where maximum distances will generally be 25 to 30km.

**Figure 5: Concept of 3-wheeler adaptation of a motorcycle**

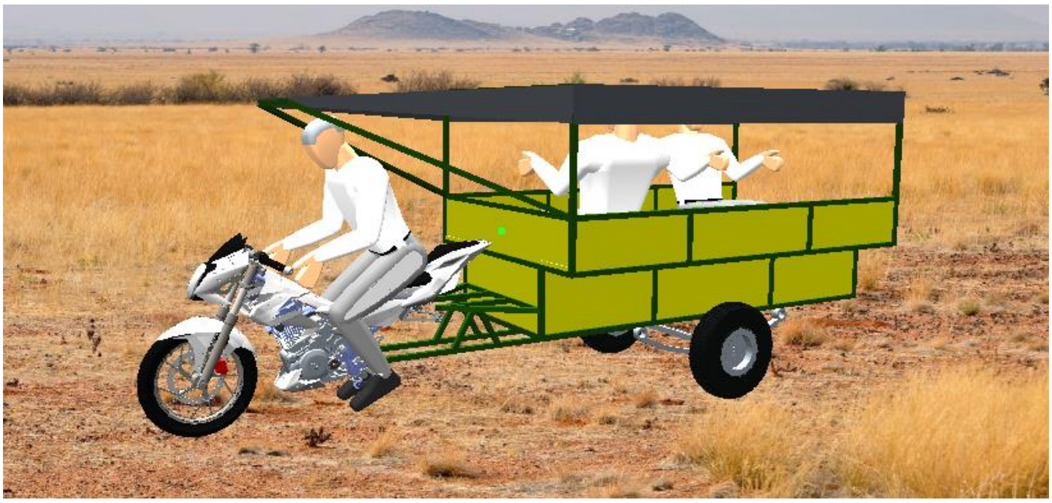


**Figure 6: Performance of 250cc MBV on earth/gravel road with 1,000kg load**

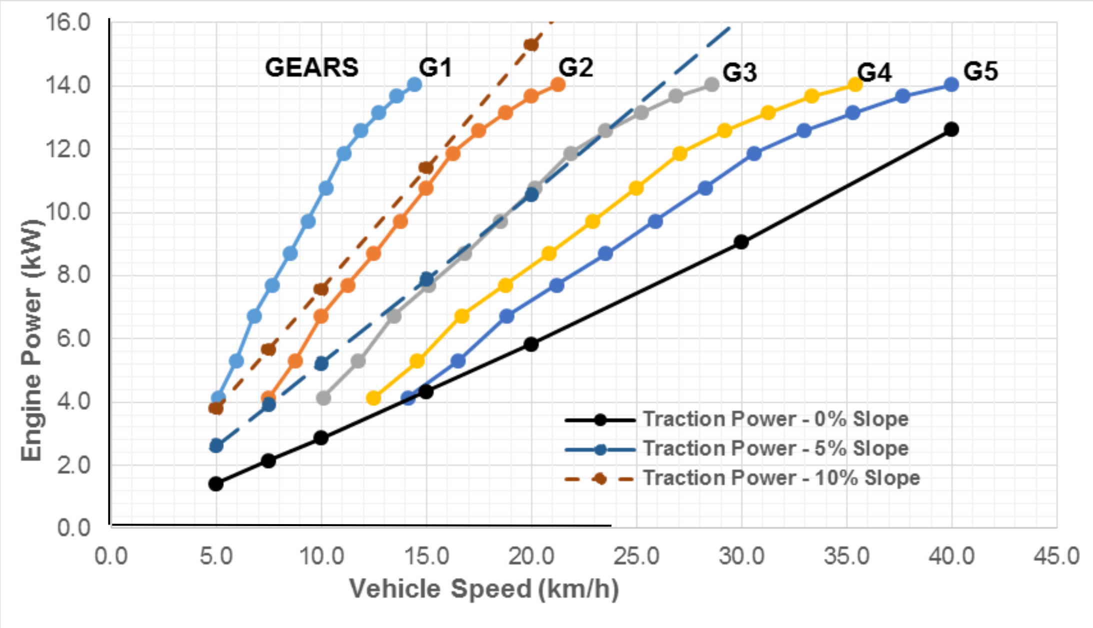
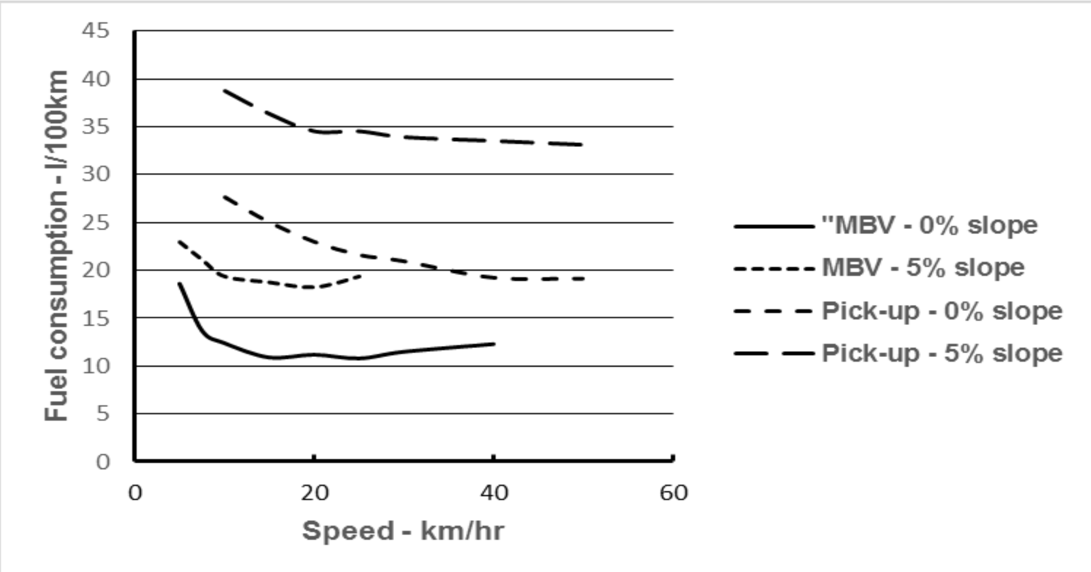



Figure 7 shows that the estimated fuel consumption of the MBV operating at an average speed of 30km/hr is around half of that of a pick-up operating at 50km/hr carrying loads of 1,000kg on earth/gravel roads. Experience from the motorcycle ambulance-trailer trials discussed below indicates that maintenance costs for a MBV will be less than half of a conventional vehicle so it can be confidently predicted that operating costs of the MBV will be at least 50% less than those of a conventional RTS vehicle, greatly increasing the possibility of running profitable RTS at affordable fares.

**Figure 7: Comparison of fuel consumption of MBV with pick-up**




An indicative break-even fare for a MBV transport service is estimated using the following assumptions:

- Fuel – 12l/100km at US$1.80/l gives $0.22/km
- Repair and maintenance – 10% of initial cost of $9,000 and 10,000km/yr gives $0.09/km

- Depreciation – Initial cost of $9,000 and life of 80,000km gives $0.11/km

Allowing for other fixed costs this gives an indicative break-even cost of $0.45 /km, or 4.5 US cents/passenger.km. Assuming 75% of income-earning capacity this increases to 6 US cents/passenger.km. Typical minibus fares for passenger with a 30kg load are reported as 7 to 14 US cents/km (Starkey et al, 2013) but it is pointed out that these probably do not allow for depreciation and are therefore not sustainable in regard to vehicle replacement and also involve excessive overloading of vehicles. Also most minibus services operate on more used routes with few on rural routes from villages. A more relevant comparison may be with motorcycle taxis which are commonly used on these routes and typically charge 20 to 25 US cents/passenger.km (ibid). It is therefore seen that MBV transport services could roughly half fares.

Vehicle emissions for RTS are of limited concern at present because of the very small numbers involved but will become of increasing significance as numbers grow and therefore need to be considered in advocating new types of vehicles. Emissions for MBV are discussed in a report by Mezler Engineering services for the International Council on Clean Transportation (Mezler, 2007). Due to less sophisticated exhaust controls emissions of noxious exhaust gases are higher for motorcycles than 4-wheel vehicles but are decreasing due to the swing from 2-stroke to 4-stroke engines – it is estimated that almost 80 % of production is now 4-stroke models. In regard to “greenhouse” gas, carbon dioxide, Mezler quotes a figure of 80g/km for a 250cc 4-stroke motorcycle. This is roughly one third of a typical passenger vehicle of 257g/km quoted by the US Environmental Protection Agency, (2014) and supports the above prediction that the introduction of MBVs would substantially reduce emissions of carbon dioxide. It might also be noted that because of the age of the conventional RTS vehicles the fuel consumption and $CO_2$ emissions are likely to be greater than those estimated.

## 4 Field trials of a motorcycle ambulance-trailer (MAT)

An example of a MBV is the MAT developed and trialled by Developing Technologies based on a concept initially developed by the author and tested in Tanzania. Figure 8 shows a MAT being used in Zambia.

**Figure 8: MAT in use in Zambia**

The MAT has the following features:

- Capacity to carry a patient on a stretcher and one or two carers. The latter is essential in many countries in sSA where carers are needed to look after patients when admitted to clinic or hospital
- Sprung suspension to improve the ride on earth/gravel roads. The suspension comprises leaf springs from a Toyota Hilux vehicle
- Car wheels with cable-operated drum brakes. These are automatically applied when the trailer pushes forward on the motorcycle by a pivotting hitch pin arrangement
- A canopy for weather protection

The MAT has been comfortably towed by a 125cc motorcycle although a 200cc model would be preferred to reduce strain on the bike. It is coupled to the motorcycle by a ball hitch mounted in a socket attached on the motorcycle as closely as possible above the rear axle. It was found from initial instrumented trials with different hitch positions that this location seemed to have the least impact on rider control of the bike. It was hypothesised that in this position the forces from the trailer tend to cause roll of the bike which is easier for the rider to control than transverse twisting moments applied when the hitch is at axle level.

Two MATs have been trialled in Zambia in the Africa Community Access Programme (AFCAP) over a period of 16 months, (Dennis and Pullen, 2015), and have continued in operation since the end of the project. The MATs were located at clinics in Lundazi District in Eastern Province and used to collect emergency patients from surrounding villages. During the project the MATs completed over 400 trips, about 60% maternity patients, and over 15,000km, greatly improving access to healthcare for the local communities and saving many lives. The average distance to a clinic in the area is 7km and the maximum about 20km. Without the MATs the villagers would be faced by lengthy and laborious trips by walking, bicycle or, in a few cases, by ox-cart. Emergency patients therefore often would not travel to the clinic because of the difficult journey or would arrive too late for effective treatment.

No safety problems were reported for the MATs. The operators reported that it took them 2 to 3 weeks to build up confidence in towing the MAT but then felt comfortable to tow it up to 40km/hr when empty and 25 to 30km/hr when full. Logbook records showed an average trip speed of 25km/hr. However, they reported that control of the bike was tiring on the arms and it was necessary to rest after about 1 hour. Other problems reported were:

- The MAT tends to bounce when empty but this disappears when loaded
- The width of the MAT makes rear vision a problem
- Some jerkiness from the overunning braking system
- Difficulty with control on some wet surfaces during the rainy season due to a loss of traction on the slippery surface

These issues will be addressed in the development of an upgraded version which it is hoped to test in Zambia next year. It is considered this further field experience is needed as a foundation for scaling up the introduction of the MAT.

The operating costs of the MAT compared to a conventional Landcruiser ambulance are shown in Table 1, based on monitoring data obtained in the Zambia project. It is seen that the initial cost of the MAT is about 10% of the cost of a Landcruiser ambulance and the total operating cost about 30%. This reinforces the estimated comparison for the RTS vehicles that the operating cost of the larger MBV would be around 50% of conventional vehicles.

**Table 1: Operating costs of the MAT**

| Ambulance Type | Initial cost (US $) | Running costs ($/km) | | | | Deprecia t'n$/km (2) | Total operating cost (3) ($/km ) |
|---|---|---|---|---|---|---|---|
| | | Fuel used km/l | Fuel cost/km (1) | Repair and maint'ce | Total | | |
| **Landcruiser** | 60,000 | 6.5 | 0.26 | 0.32 | 0.58 | 0.26 | 0.84 |
| **MAT with 125cc m/c** | 5,500 | 28 | 0.06 | 0.12 | 0.18 | 0.08 | 0.26 |

**Notes**

1 Based on fuel price of $1.7/litre;

2 This is the annual replacement cost based on 4% inflation and assuming –
(i) Landcruiser - 25,000km/yr and total life 300,000km

(ii) MAT– 10,000km/yr and total life 80,000km

3 Other costs may include annual road tax and insurance (depending on Government requirements), operator costs and protective clothing for riders

## 5 Conclusions

The paper shows that MBVs have great potential to provide effective and profitable transport services at affordable fares in rural areas of sSA. If geared down to an appropriate maximum speed of 40km/hr, MBVs based on a 250cc motorcycle can comfortably carry or tow loads up to 1 tonne, equivalent to 10 persons and their goods, on rural earth/gravel roads making them very appropriate for providing RTS linking villages to markets and other facilities. The operating costs are estimated to be around 50% of conventional RTS vehicles greatly increasing the potential for setting up economically viable RTS.

It is envisaged that the widespread introduction of RTS using MBVs will have a major impact on increasing the mobility of rural people in sSA, leading to improvements in livelihoods and on rural economies. Service operators will need to develop routes and schedules that provide reliable, convenient and regular services for rural communities to maximise usage so that services can be run at a profit whilst keeping fares affordable. It seems likely that these will initially be based on market days enabling families to carry more goods to market with a much reduced burden of time and effort but as incomes grow there will be increasing usage for other purposes, therefore increasing the viability of the services.

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## Response to reviewer comments

**Reviewer 1 –** comment on social impact

The following paragraph has been added to the Conclusions

It is envisaged that the widespread introduction of RTS using MBVs will have a major impact on increasing the mobility of rural people in sSA, leading to improvements in livelihoods and on rural economies. Service operators will need to develop routes and schedules that provide reliable, convenient and regular services for rural communities to maximise usage so that services can be run at a profit whilst keeping fares affordable. It seems likely that these will initially be based on market days enabling families to carry more goods to market with a much reduced burden of time and effort but as incomes grow there will be increasing usage for other purposes, therefore increasing the viability of the services.

**Reviewer 2**

1 Impact of Nitrous Oxide emissions

The following sentence has been added at the end of Section 2

Increased nitrous oxide emissions are also of concern, particularly where roads pass through villages.

2 Typo – this has been corrected

3 Figure 7 in clour

The actual publication will be in black and white

| Ambulance Type | Initial cost (US $) | Running costs ($/km) | | | | Deprecia t'n$/km (2) | Total operating cost (3) ($/km ) |
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**Table 1: Operating costs of the MAT**

## List of figures



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