
Title: The Impact of Road Surface Condition on Rural Transport Services

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Abstract

The Impact of Road Surface Condition on Rural Transport Services

In most low-income countries, the movement of goods and people is largely dependent on road transport.

Many African countries are classed as “low-income” countries, and the highest proportion of the road network is either earth or gravel roads. Due to a dwindling supply of natural gravels, these roads are increasingly more difficult to maintain sustainably. Moreover these earth and gravel roads mostly lead to agriculturally productive areas; it is common knowledge that agriculture is the main contributor to the gross domestic product of many African countries.

Improving the road surface condition of these strategic links provides access to cheaper and more efficient transport services for the rural and peri-urban communities. This improved access has a significant impact on the economic and social well-being of households. In turn, the summation of these impacts has a strong bearing on the national economy.

This paper is based on a case-study of a road improvement project carried out in Ethiopia. The road improvement works were carried out between 2007 and 2016. The results show that improvement of the surface standard of a gravel road to a paved standard led to an immediate increase in the number of trips of public transport vehicles. The increase in number of trips provided opportunities for cheaper transport fares for the local community and in turn encouraged more travel to support economic and social activities. The study also showed that if a road surface condition deteriorates significantly, certain types of public transport vehicles either stop the provision of services or decrease the number of trips made.

It is therefore important to maintain the rural road conditions to carefully selected performance thresholds in order for public transport services to thrive and support the socio-economic well-being of the rural communities, and in turn the economy of the country.

Keywords

Roads & Highways; Public Transport; Rural Roads; Road Condition

Notations:

ADT: Average Daily Traffic

AADT: Annual Average Daily Traffic

BHP: Brake Horse Power

cc: cubic centimetre

IRI: International Roughness Index

kg: kilogram

km/h: kilometre per hour

m/km: metres per kilometre

mm: millimetre

vpd: vehicles per day

1. Introduction

A significant proportion of roads in Africa are unpaved. Trans-Africa Consortium (2008, p. 73) estimated the percentages (as a proportion of the total road network length) of the road length that are paved to be only 22.6% in western Africa; 20.7% in southern Africa; 9.5 % in eastern Africa; and 4.1 % in central Africa; by the year 2008. In addition, Gwilliam, Foster, Archondo-Callao, Bricenco-Armendia, Nogales and Sethi (2008) argue that a large number of countries in sub-Saharan Africa are not devoting enough resources to maintain the road network, and that some are not even spending enough to meet routine maintenance demands. Their study also shows that only 2 out of 21 countries in sub-Saharan countries in Africa reported more than 50% of the rural road network as being in “good” condition. Moreover, these countries use different standards to classify the condition of their roads.

In Ethiopia, the current proportion of paved roads compared to the total classified standards roads is 20.7%. If the URRAP (Universal Rural Road Access Program) roads are considered the proportion of the paved roads will be 12%. URRAP roads are low-standard access roads constructed to connect the rural communities to all weather roads, market places, health and administrative services. Therefore, the proportion of paved roads in Ethiopia is above the estimated paved roads proportion for Eastern African countries. However, it can be concluded that this proportion is very low considering the other parts of Africa as well as the area of the country - which is one of the top ten largest countries in Africa with 1.1 million square kilometres of surface area.

Nevertheless upgrading of roads from earth to gravel, or gravel to paved standard does occur in many of these countries. However, in carrying out these improvements, it is not unusual to forget about the kind of traffic composition that will be using the road, or for whom the road is intended, or any new types of vehicles that may begin to use the improved road. One may thus forget that the kind of road surfacing provided or the geometric features provided significantly influences the type of vehicles that are able to use the road. Buses for instance are not able to climb or safely descend steep roads of more than about 10% gradient.

2. Importance of a good road condition

Road condition affects the speed at which vehicles travel and the riding quality experienced at different speeds. Ridding quality is greatly influenced by road roughness which is measured in terms of the international roughness index (IRI). IRI is defined as a ratio of a standard vehicle’s accumulated suspension motion (in metres) divided by the distance (measured in kilometres) travelled by the vehicle during the measurement. Its units are thus metres per kilometre (m/km). A study by Singh and Burgess (1991) showed that for light vehicles, vertical vibrations contributed more significantly to ride quality and damage in light vehicles than lateral and longitudinal vibrations, hence is the focus on roughness in this paper. Thus in fighting global poverty and in providing rural access, the condition and the riding quality of the roads should be given due consideration.

From the preceding paragraph, it is evident that roads with high IRI will have a high effect on vehicle suspensions. At some point suspension damage to vehicles using the road will inevitably occur. Therefore, this is an operating cost whenever the vehicles are maintained. As a result commercial vehicle operators would either increase the cost of transportation to uneconomical levels or they would stop operating altogether if the IRI of a road increases significantly. A study by Steyn and Bean (2013) showed that inadequate ride quality increased freight costs because of increased fuel consumption, tyre wear and damage, and vehicle damage. The study used IRI as a measure of the ride quality but focussed only on freight transport.

Road condition also has a significant effect on the state at which farm produce is delivered to the market. For example a road that has sections which are impassable for several days, means perishable agricultural produce such as tomatoes, bananas, and cabbages may rot before they arrive at the market, thus depriving the rural farmers of income. It has been shown by Steyn, Nokes, du Plessis, Agacer, Burmas, and Popescu (2015) that about 29% of tomatoes were damaged when transported at a speed of 30 km/h on roads of IRI of 6 m/km. This quantity of damage would highly affect the income of the rural poor population for whom access is provided for the economic purpose of transporting goods to markets. Poelman and Weir (1990) also argue that suspension fatigue damage occurs on road surfaces with present serviceability index (PSI) less than 1.5. According to correlations developed by researchers such as Hall and Correa (1999) a value of 1.5PSI equates to IRI of about 7.4 m/km. Poelman and Weir (1990) further urge that: 'road planners should be aware of the point at which the operator may experience significant damage'. However, these studies focus on heavy goods vehicles and not on passenger transport or light and very light vehicles. Transport of goods has been severally studied but rural-urban passenger transport in relation to a quantity such as road roughness has scarcely been studied, hence the motivation for this study.

This paper shares the results of a study conducted in Ethiopia and proceeds to recommend standards to ensure a good mix of all vehicle types in rural transport.

3. Characterising road roughness

Previous work by the World Bank groups road roughness in the following categories shown in Table 1.

Table 1 Interpretation of road roughness values

Roughness	Comment
1.5-3	Ride comfortable up to 120km/h
4-6	Ride comfortable up to 100km/h
7-8	Ride comfortable up to 70-90km/h. strong perceptible movements. Occasional potholes
9-10	Ride comfortable up to 50-60km/h. Sharp movements and swaying. Deep and uneven depressions, and frequent patches and potholes
>10	Necessary to reduce speed below 50km/h. Deep depressions, potholes and severe disintegration.

Adopted from (Sayers & et al, 1986)

Table 1 may be used in three major ways: To estimate the roughness of a road from the maximum comfortable speed at which one is able to drive on the given road; or to estimate the likely surface condition of a road from a given roughness index; or to set standards that IRI should be maintained at on the road network.

4. Case Study: Morocho – Leku road, Ethiopia

4.1 Location

Morocho – Leku road is a 3.3 km road that connects the town of Morocho (located on the trunk road from the City of Hawassa to the town of Dilla) to the town of Leku located further inland. The town of Leku is located about 30 km from Hawassa City of Ethiopia's Southern Region. Leku has a very high population density of about 300,000 in a town of area about 8 square kilometres. The main economic activity in the area is crop farming. The area is major supplier of potatoes, grains, coffee, and fruits to Hawassa City and to Addis Ababa City.

4.2 Immediate impacts of upgrading of Morocho – Leku road

The road from Hawassa to Morocho is a paved bituminous trunk road. In 2008, significant lengths of the road from Morocho to Leku were upgraded to bituminous standard. Figure 1 shows the variation of average daily traffic (ADT) with road roughness for this road before and after it was upgraded.

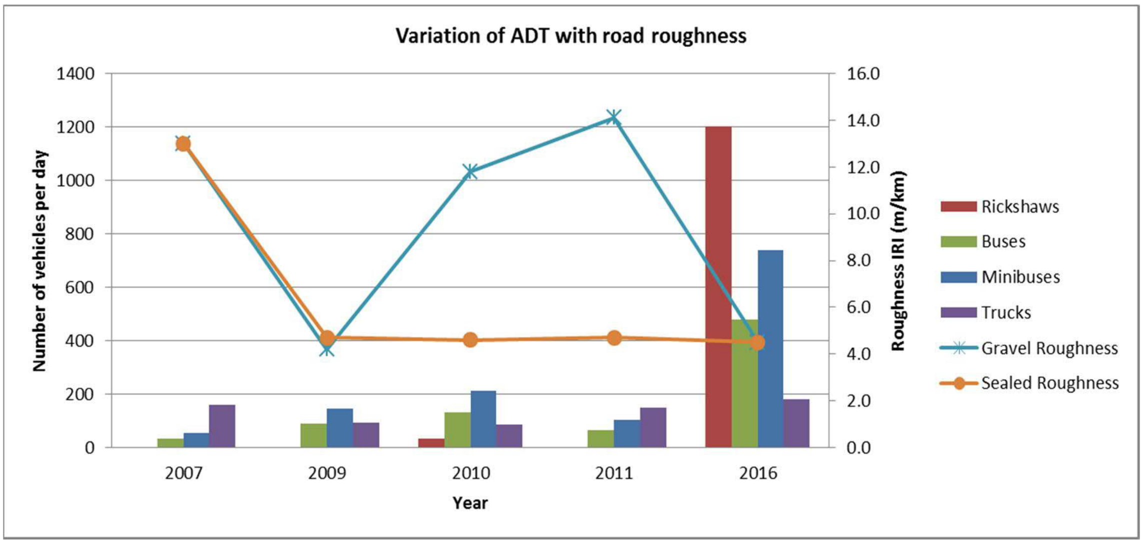


Figure 1 Variation of ADT with road roughness

In 2007, the 3.3 km road had a gravel wearing course for its full length. From the bar chart in Figure 1, the ADT in 2007 for buses was less than 100 vehicles per day (vpd). The road roughness at that point was about 13m/km. From Table 1, it can be deduced that in 2007 the road was severely disintegrated with deep depressions and potholes, and speeds had to be maintained below 50 km/h. In 2008 the road was upgraded to a sealed bituminous road, but a short gravel section was left in the middle of the road link for experimental reasons of gravel materials. That is, Section 1 of 700 m was upgraded to a bituminous standard; Section 2 of 650 m was graded, re-shaped and re-compacted but left as a gravel road; and section 3 of 1900 m was also upgraded to a bituminous standard. From Figure 1, the roughness represented by the line graph, reduced from 13 m/km to about 5 m/km for the whole road length including the gravel section. At this level of roughness, Table 1 shows that comfortable driving can be maintained for speeds of up to 100 km/h. This roughness value is comfortable for all forms of vehicles, hence the increase in bus ADT and the subsequent introduction of commercially operated rickshaws. The total bus ADT (buses and minibuses) rose from about 80vpd to about 230vpd. Figure 1 shows that in 2007 when the road was very rough there were more trucks than buses. Trucks are normally used to transport people and their goods on rough roads - because they are more robust for use in poor road conditions.

In 2009 the total number of bus ADT increased almost 200% while the number of trucks dropped approximately 50%. A similar trend is shown in 2010. However, in 2011 when the gravel section (Section 2) had become very rough (IRI of 14) the number of buses had decreased significantly (approx. 30% compared to 2010) and the number of trucks increased significantly (approx. 50%) compared to 2010.

4.3 Different vehicles affected differently by the same value of roughness

Although, rickshaws started using the road in 2009, their ADT was only recorded in 2010 when some had already withdrawn; at this point the sealed (bituminous) road sections roughness was still about 5 m/km, whereas the gravel section roughness had risen to about 12 m/km. This value of roughness is very uncomfortable for driving and most dangerous to rickshaws due to their small tyres and weak suspension systems, hence the total withdrawal of the rickshaws in the year 2011.

Figure 2 shows how the same value of road surface roughness affects rickshaws more adversely than it affects buses and other vehicles with bigger wheel diameters and tyre tread widths.

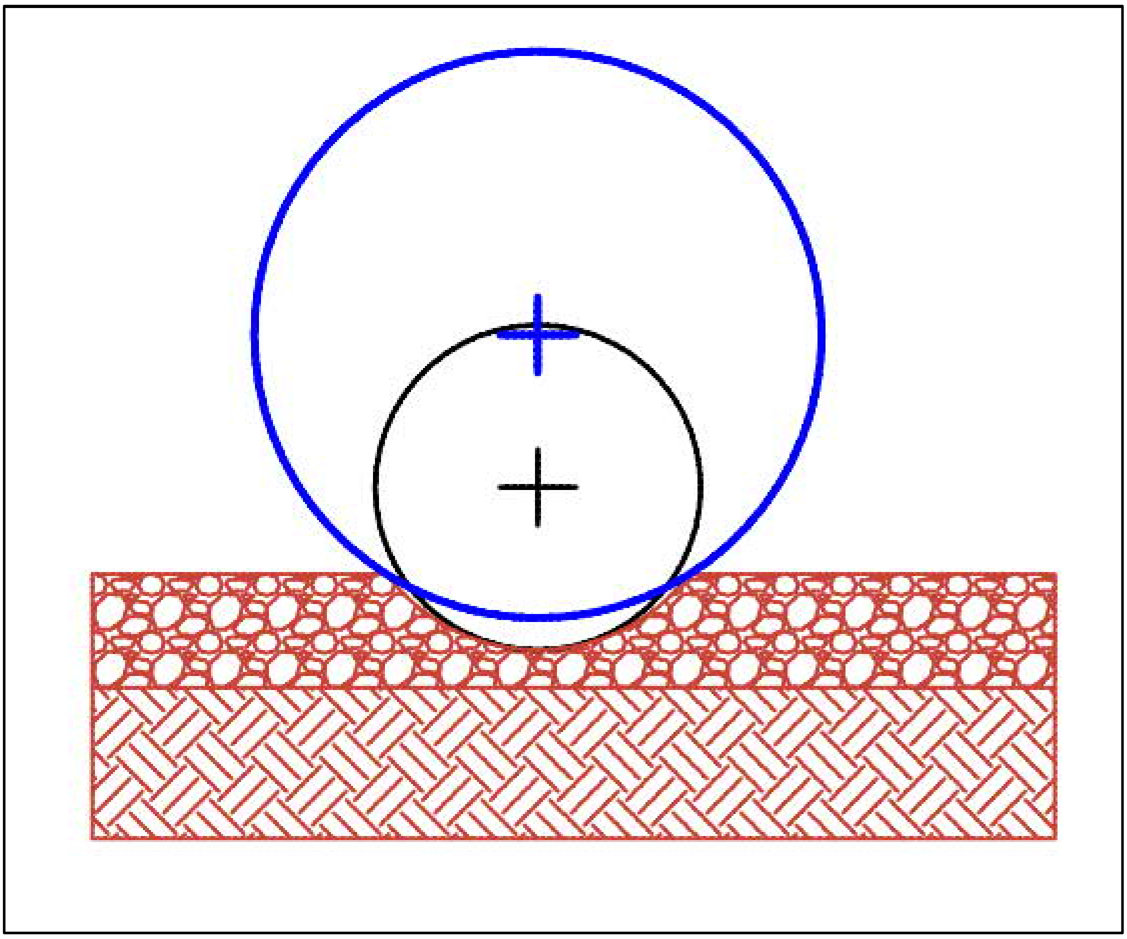


Figure 2 Comparison of the effect of road roughness on rickshaw wheel vs a minibus wheel

Consider a rickshaw of typical wheel diameter 435 mm represented by the black circle in Figure 2, and a minibus of typical wheel diameter 750 mm represented by the blue circle. If a pothole of diameter 400 mm and depth 100 mm exists on the road surface, a rickshaw wheel would fully enter into the pothole thus experiencing a vertical displacement of 100 mm; conversely a minibus wheel would only partially enter into the pothole experiencing a vertical displacement of about 60 mm. These vertical displacement values have been determined through geometry. Moreover, a loaded rickshaw weighs about 600 kg; with an engine capacity of 200 cc (12 BHP), it means only 0.33 cc per kg (0.02 BHP per kg) of load is available. A minibus which weighs about 3000 kg loaded, with an engine capacity of 2500 cc (100 BHP), has about 0.83 cc per kg (0.033 BHP per kg) of load available. In summary the rickshaw is affected more by roughness and it is also considerably weaker in carrying load. In addition to this, the rickshaw engine easily overheats when it is ascending steep gradients.

Despite all this, a rickshaw offers many advantages to owners and users. It is cheaper to purchase and maintain compared to a minibus, and due to its small size it fills up with passengers quickly thus reducing the waiting time at the stops at only a fraction costlier than buses and minibuses (between Morocho and Leku, the cost is 3 Birr by rickshaw and 2 Birr by minibus or bus). It is worth noting that at the moment 1 US dollar is equivalent to about 23 Birr.

4.4 Further work on Morocho-Leku

In 2015, the gravel section (Section 2) of 650 m was upgraded to a bituminous standard and the full road length from Morocho to Leku received another bituminous overlay. The IRI of the road length reduced to 4.5 (including the gravel section whose roughness was more than 14 IRI). This improvement led to a re-introduction of rickshaws and a high increase in the number of trips of buses and minibuses on the route as seen in Figure 1. Of greatest significance is the number of trips made by the rickshaws.

In August 2016, 10 bus drivers, 12 minibus drivers, and 25 rickshaw drivers that operate the Hawassa – Morocho – Leku route where interviewed. The rickshaws interviewed only operate between Morocho and Leku. The results of the interview are summarised in Table 2 and Table 3.

Table 2 number of years of operating on the Morocho - Leku route by different vehicle types

Vehicle Type	**2016 Number of Drivers /Years Operating on Road**				
	≤2	2<x<5	5<x<8	8<x<11	>11
Rickshaws (Bajajs)	22	2	1	0	0
Minibus (Hiace)	3	8	1	0	0
Bus (Isuzu)	2	0	4	0	4

From Table 2, it can be seen that in general most drivers started operating on the route less than 8 years ago. This coincides with the first upgrade carried out on the road. Also among the rickshaws most of them started operating on the route less than two years ago – coinciding with the full upgraded of the road. Minibuses too have all been operating on the road for less than 5 years. The buses though have been operating on the route for longer, even for more than 11 years when the road was still in bad condition.

4.5 Why public transport operators are attracted to the route

In order to find out the reason for the different durations that drivers have been operating on the route, they were asked to state the reasons why they were attracted to the route. It was an open-ended question without suggesting possible reasons to the drivers. In addition, each driver was interviewed independently so as to reduce the possibility of being influenced by their colleagues' reasons. The reasons have been summarised in Table 3.

Table 3 Reasons for operators being attracted to Morocho – Leku route

Reasons for being attracted to route	Number of times cited		
	Buses	Minibuses	Rickshaws
High number of passengers	6	4	16
Good quality road	7	4	16
Local resident	5	1	0
Trip is short (good speed)	2	4	0

It is seen from Table 3 that the high number of passengers and the good quality of the road are the major reasons for attracting these public transport operators to ply a given route. The reason for "the good quality of the road" is further supported by the fact that there are no operators that use the shorter route A-C (see Figure 3) to travel between Hawassa and Leku. Route A-C is a 7 km rough gravel road of estimated IRI 12 whereas A-B-C (12 km long and IRI 5) is the route of choice among all the bus and minibus drivers interviewed.

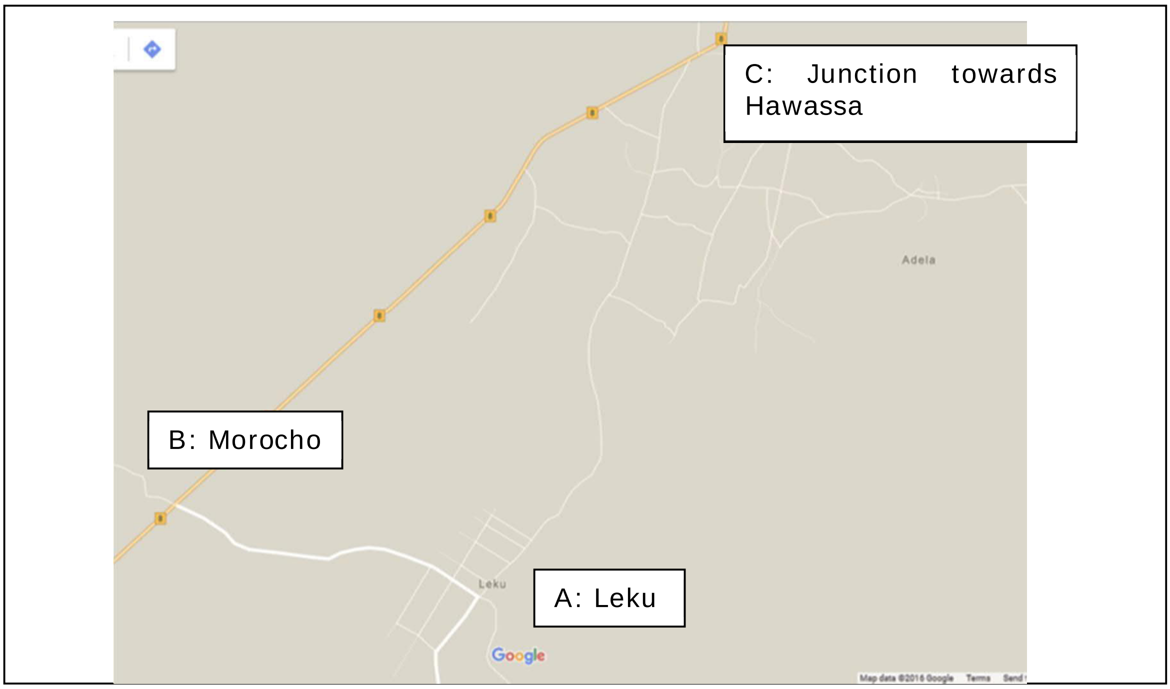


Figure 3 Route choices made by operators

4.6 Influence of the road surface condition on number of trips made and fares

Another factor of interest was the number of trips made by the different vehicle types at the times when the road was in poor condition as compared to when the road was in a good condition. This is shown in Figure 4. It is seen that there is a significant difference between the number of trips the rickshaws are able to make when the road is in good condition (18 trips per day) as compared to when the road is in a poor condition (13 trips per day). It should be remembered that during the interview, only 2 rickshaw drivers were able to operate when the road was in poor condition, hence they were able to make more trips since the competition of other rickshaws was non-existent. Interestingly, the number of trips made by the buses is the same for both the poor road condition and the good road condition periods. The bus drivers interviewed gave the reason for this as the increase in the number of rickshaws and minibuses which are preferred by passengers because they fill up fast. As a result the additional trips the buses would have made in good road condition are taken up by the rickshaws and minibuses.

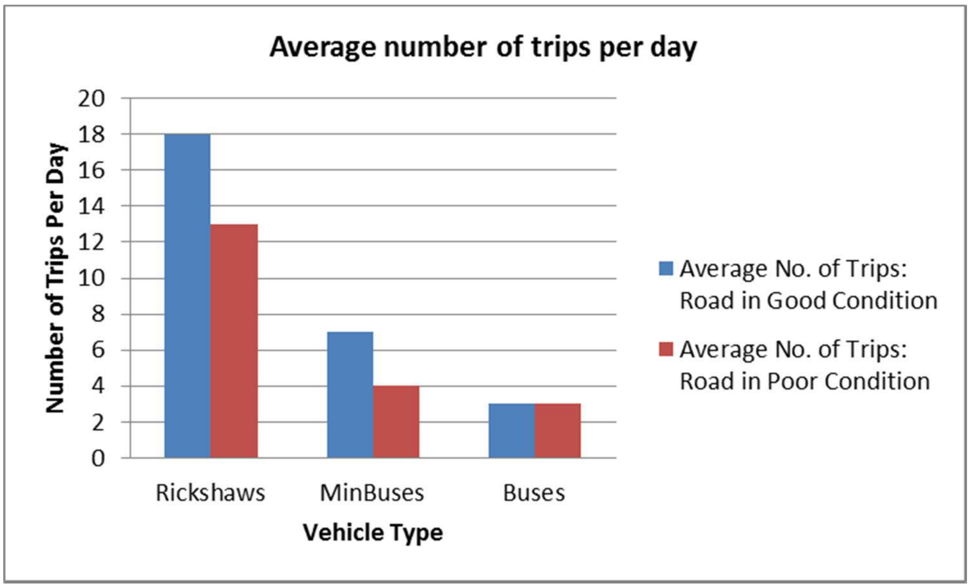


Figure 4 A comparison of the number of trips per day during poor road condition and during good road condition

The transport fare between Morocho and Leku between the different vehicle types and the road conditions was also compared (see Figure 5). Buses and minibuses have maintained the same fare during both poor and good road conditions. When asked why they had not increased the transport fare for all these years, the drivers mostly said it is because the competition is high but also that they are benefiting because their vehicles no longer breakdown as frequently as when the road was in poor condition.

The rickshaws however were charging 5 Birr when the road was in poor condition but reduced this to 3 Birr when the road was upgraded. The reason they give is that when the road was in poor condition they were carrying out frequent maintenance on their vehicles and therefore charged extra in order to cater for this cost. They said that they now charge 1 Birr more than buses and minibuses because their (rickshaws) vehicles fill up faster and hence passengers do not have to wait for long before setting off.

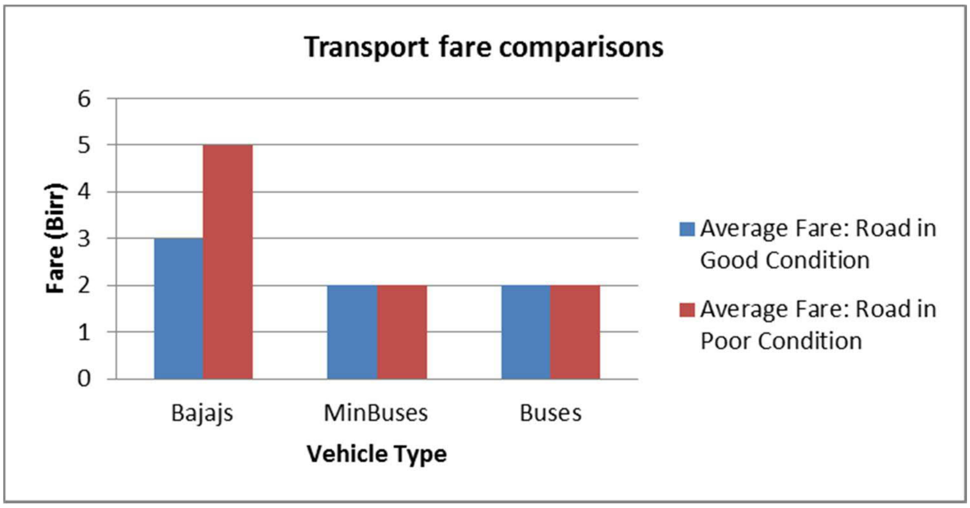


Figure 5 A comparison of the transport fares per trip during poor road condition and during good road condition

Other remarks made by the interviewed drivers:

Bus drivers:

- None of them stopped operating when the condition of the gravel section deteriorated
- When the road condition was poor their vehicles often suffered broken suspension systems
- They blamed the 10-wheel trucks for destroying the roads

Minibuses:

- Three out of 12 of them stopped operating when the condition of the gravel section deteriorated

Rickshaws:

- They were affected by a combination of steep gradient and poor road condition
- When the road was initially improved, 5 rickshaw operators where present, but as the condition of the gravel section worsened, only 2 of them continued operating; eventually one of the two switched to using a motorbike to transport passengers.

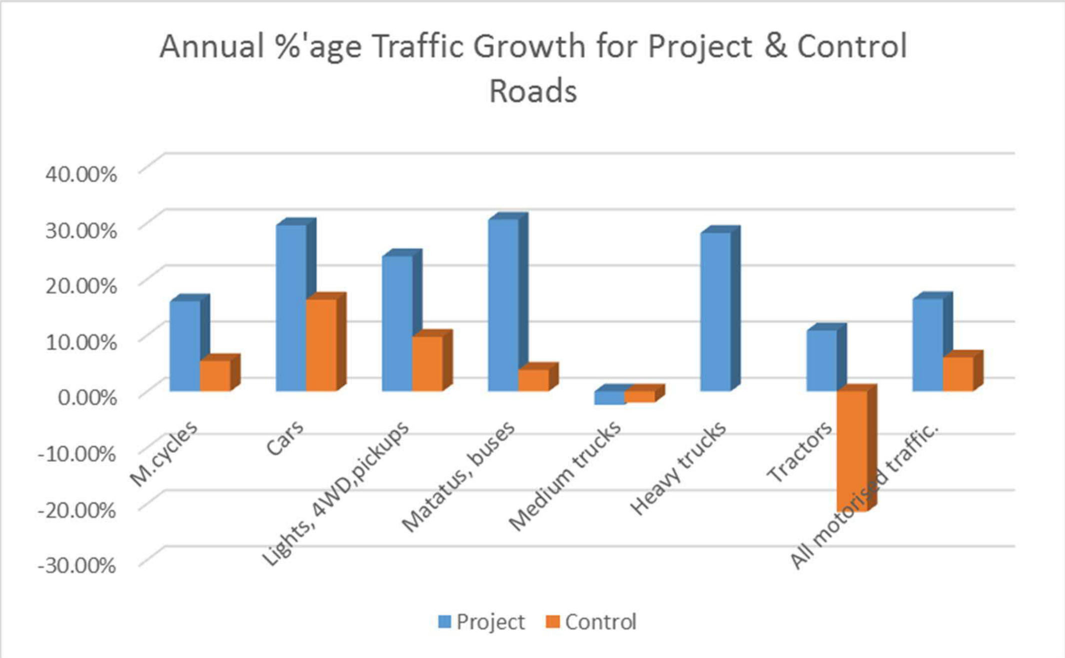
5. Comparison with Kenya

A study by Hine and Bradbury (2016) was carried out on behalf of Agençe Francaise de Développement (AFD) to assess the impact of the "Roads 2000" programme in Kenya of upgrading gravel roads to paved standard. The study focused on 12 roads; 8 project roads (paved) and 4 control roads (gravel). To account for other factors (for example differences in economic growth) that could influence the growth in traffic, the study was carried out within the same region (Central Region) in Kenya and the control roads were selected close to the vicinity of the project roads. The project and control roads were also of similar length in similar terrain in rural to urban settings. The Ethiopian case also involved a road in a rural to urban setting; hence, it is comparable on that basis. The Kenya study also reported that since the improvement works (in 2014) on the project roads, there was an average annual growth of 16.5% in motorised traffic on project roads compared to rate of 6.1% on control roads. The reason for the difference can therefore be attributed to the improvements carried out on the project roads.

Similar to the Ethiopian case, upgrading of gravel roads to paved standard led to significant traffic growth among most of the vehicle types. In Figure 6 (taken from the Kenya study), it is seen that all project roads showed an increase in all vehicle types compared to the control roads. Amongst the passenger transport modes, the highest difference in growth rate between the project roads and the control roads was observed for the medium buses (Matatus) and buses class.

In addition to this, there was also a large increase in the growth of heavy trucks for the project roads. Heavy trucks usually carry agricultural produce, merchandise and construction materials. This means that when a gravel road is upgraded to paved standard, the frequency of public transport for passengers and goods increases significantly; and this is good for the socio-economy of the communities and for the national economy in turn.

Of course the major difference between paved bituminous roads and gravel roads is that the bituminous roads retain a low value of roughness for a long time compared to gravel roads (see Figure 1).



Source: (Hine & Bradbury, 2016)

Figure 6 Annual traffic growth rates of “Roads 2000” project roads in Kenya

6. Ethiopia’s gravel road condition

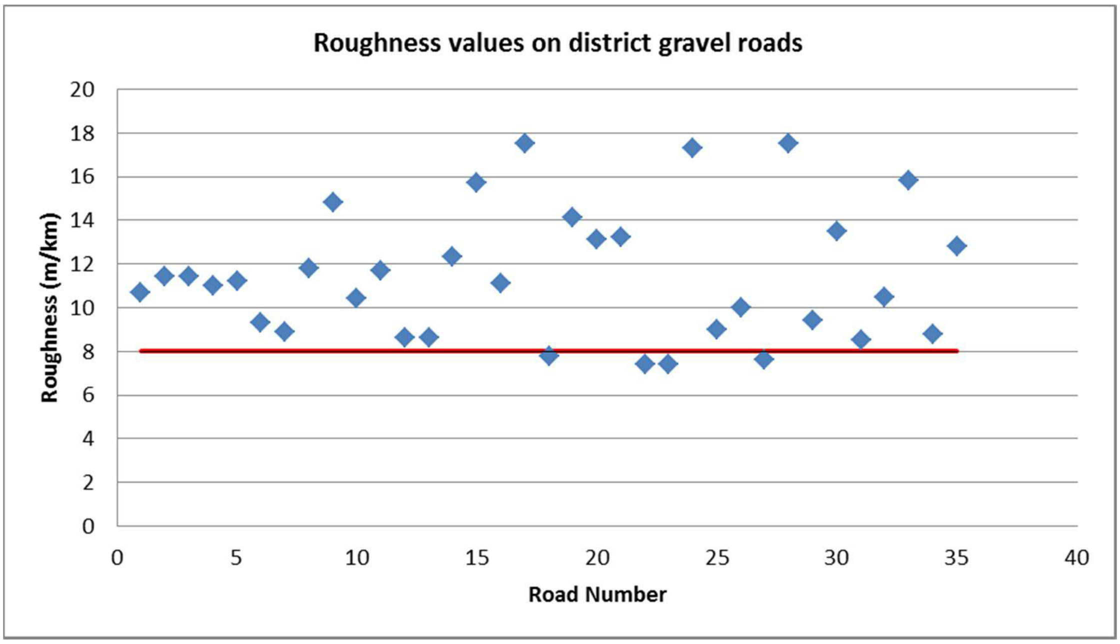
Ethiopia recently revised its gravel road condition rating system as shown in Table 4. The major change is that the new gravel road rating is stricter than the previous.

Table 4 Ethiopian Roads Authority road condition rating scale

IRI Limits		
New Gravel Roads Rating	**Previous Gravel Roads Rating**	**Bituminous Roads (Asphalt Concrete) Rating**
< 4 Very Good	< 6 Very Good	< 2 Very Good
4 – 6 Good	6 – 9 Good	2 – 3 Good
6 – 8 Fair	9 – 12 Fair	3 – 4.5 Fair
8 – 12 Poor	> 12 Bad	4.5 – 6.5 Poor
>12 Very Poor		> 6.5 Very Poor

Source: Ethiopian Roads Authority

A gravel road is only acceptable (Fair Condition) if its IRI is less than 8. The previous rating for Fair Condition required that the IRI should be less than 12. At an IRI value of 12 or higher, rickshaws have difficulty in operating whereas at an IRI of less than 8 rickshaws are also able to operate frequently on a given route (see Figure 1). The revision of the condition classification is therefore a step in the right direction. The challenge is for the roads maintenance units to maintain the roads in Fair Condition, or better. This is seldom achieved. Figure 7 shows the results of a survey of the roughness of roads in a typical maintenance district in Ethiopia carried out as part of a larger study (Performance Criteria and Life-cycle Costing Study). The horizontal axis shows proxy road numbers of the individual roads on which the study was conducted, whereas the vertical axis shows the IRI measured on each of the roads in the study. From Figure 7, it can be seen that only very few roads at any given time have an IRI of less than 8, as seen from the number of points below red line in Figure 7. This therefore means that the surface condition (expressed in terms of IRI) of the majority of gravel roads in the particular district, as well as in other similar districts would not be conducive for rickshaws to operate in.



Source: Developed from (Mukura, 2008)

Figure 7 Distribution of road roughness in a maintenance district in Ethiopia

The best solution in keeping the IRI below 8 is of course to pave all gravel roads and provide bituminous or concrete surfacing, but this cannot be achieved easily due to the current large network lengths of gravel roads. A strategy of upgrading selected roads every year could help to achieve this by enabling a staged progress. If the roads in areas of large populations and agricultural productive areas are upgraded regularly, the economy will improve and the cycle of improvement is then completed. It is easy to achieve a gravel road condition of IRI less than 8 through regular grading. However, in trying to achieve maintenance standards authorities must bear in mind that the highest standard may not necessarily be the most cost-effective method as shown by Chamorro and Tighe (2015). Table 5 shows gravel qualities A (best) to D (worst) and the effect of grading on the roughness of gravel roads constructed with materials of these qualities. As an example, the biggest effect was realised by grading the road in the last row of Zone B. In this case, the IRI value decreased from to 10 before grading to 6.9 after grading. Therefore, maintenance districts should focus on frequent grading and re-compaction. If compaction is carried out after grading, the improved condition would last longer.

Table 5 Impact of grading on roughness of gravel roads

Zone	Roughness Before Grading (RI_{bg})	Roughness After Grading (RI_{ag})	Decrease in Roughness due to Grading (dIRI)
A	6.0	4.5	1.5
	7.0	5.2	1.8
	8.0	5.9	2.1
	9.0	6.6	2.4
	10.0	7.3	2.7
B	6.0	4.2	1.8
	7.0	4.9	2.1
	8.0	5.6	2.4
	9.0	6.2	2.8
	10.0	6.9	3.1
C	6.0	5.1	0.9
	7.0	5.9	1.1
	8.0	6.7	1.3
	9.0	7.4	1.6
	10.0	8.2	1.8
D	6.0	4.4	1.6
	7.0	5.0	2.0
	8.0	5.7	2.3
	9.0	6.4	2.6
	10.0	7.1	2.9

Source: (Mukura, 2008)

Another strategy is to select materials used for construction of gravel wearing courses carefully. The Ethiopian Low-Volume Roads Manual currently has specifications for selecting wearing course gravels to reduce road roughness and gravel loss at the same time. The selection specifies the maximum particle size of the gravel, plasticity characteristics, and fine particle limits.

7. Conclusions

It is known that road surface roughness significantly impacts on vehicle operating costs. Equations exist that calculate transport costs as a function of roughness. Much as drivers may not be able to perform these calculations, they are aware of the implicit costs of a road with high roughness. If these drivers are operating commercial public transport vehicles, they will not provide services on roads with high roughness or if they do provide the services, the charges to the rural poor shall remain high and uneconomical. This hinders the movement of the rural poor and of market goods, and consequently the fight against global poverty.

A critical value of 8 m/km of road roughness has been determined (based on the roughness at the time rickshaws began to withdraw) as the figure above which a significant fall in provision of transport services either by minibuses or by rickshaws begins to fall. The drivers interviewed along Morocho – Leku road stated that they were attracted to operate on this route because of the good road condition. Roads agencies must aim to keep the road network roughness below this value through regular grading and compaction of gravel roads and through progressively providing bituminous seals for strategically selected roads in the network. Most transport services providers are more attracted to sealed low volume roads as the roughness and dust is significantly reduced. Small transport service vehicles and rickshaws feel encouraged to use sealed rural roads even if the terrain and geometry is not favourable. However, sealing low volume rural roads is not an option that is considered feasible by most road agencies, though this attracts more transporters.

Another factor that is crucial for public transport services to thrive is the presence of high population as seen in the Morocho – Leku road case study. This was determined through the feedback from interviews of drivers operating along the route. Thus if road upgrading projects are to be carried out, the population size serviced by candidate roads should have a strong weighting in the selection criteria.

Recommendations

As shown in this study, sustained low roughness of roads and high population attract a large number and wide range of transport service providers; including rickshaws. The best way to achieve a sustained low value of roughness on rural roads is to provide a bituminous seal to protect the road surface from rapid deterioration. It is recommended that roads authorities should carry out progressive sealing of gravel roads on a yearly basis. It is recommended that roads linking high population areas to towns, roads to agriculturally productive areas, and roads with high annual per kilometre cost on grading and regravelling should be given high priority. It is not possible to seal all gravel roads at once, it is therefore recommended that gravel roads that cannot be sealed immediately should be maintained at roughness values well below 8 m/km through regular grading followed by compaction. Regravelling should be carried out at times whenever the gravel thickness falls below 50 mm.

A further study should be carried out on the impact of road surface condition on movement of agricultural goods.

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Figure captions

Figure 1 Variation of ADT with road roughness

Figure 2 Comparison of the effect of road roughness on rickshaw wheel vs a minibus wheel

Figure 3 Route choices made by operators

Figure 4 A comparison of the number of trips per day during poor road condition and during good road condition

Figure 5 A comparison of the transport fares per trip during poor road condition and during good road condition

Figure 6 Annual traffic growth rates of "Roads 2000" project roads in Kenya

Figure 7 Distribution of road roughness in a maintenance district in Ethiopia

Table Captions

Table 1 Interpretation of road roughness values

Table 2 number of years of operating on the Morocho - Leku route by different vehicle types

Table 3 Reasons for operators being attracted to Morocho – Leku route

Table 4 Ethiopian Roads Authority road condition rating scale

Table 5 Impact of grading on roughness of gravel roads