A STUDY OF THE COST-EFFECTIVENESS OF GRADING UNPAVED ROADS IN DEVELOPING COUNTRIES

By T E JONES and R ROBINSON

The work described in this Report forms part of the programme carried out for the Overseas Development Administration, but the views are not necessarily those of the Administration.
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A STUDY OF THE COST-EFFECTIVENESS OF GRADING UNPAVED ROADS IN DEVELOPING COUNTRIES

ABSTRACT

Costs are determined for the maintenance of unpaved roads using motor graders, tractor/towed graders and tractor/mechanical drags based on field work in Africa. The cost-effectiveness is highlighted of using tractor/towed grader combinations for the maintenance of properly constructed roads which are not badly deteriorated.

Typical values of maintenance equipment availability for developing countries are given and the effect that this has on the cost of maintenance is determined.

A method is proposed for determining optimum grading frequencies for roads using computerised investment models and this has been included in a recommended management method for recurrent maintenance. A grading frequency chart is developed for use by maintenance engineers in developing countries who do not have access to computer methods.

1 INTRODUCTION

The principal operation in maintaining unpaved roads is grading which can be carried out either with a motor grader or towed grader. In addition, dragging may be carried out with the objective of controlling corrugations, and light or routine grading is also carried out for this reason. Heavy grading is used to reshape the road surface and to restore it to its correct camber or crossfall and to provide a smooth running surface. This activity normally includes watering and compaction. Heavy grading can be combined with regravelling to restore the thickness of the gravel surface. Filling or patching of local deformation are labour-intensive operations to deal with the worst defects on low-volume roads for which the expense of grading or other machine activities cannot be justified.

TRRL Overseas Unit have recently carried out studies of unpaved road deterioration and maintenance in Ghana (Roberts 1983, Roberts and Gaituah 1983) and Kenya (Jones 1984). The Ghana Study examined current maintenance practices in the country and investigated levels and rates of deterioration of the gravel road network. In addition to studying these items, the Kenya study also investigated the use of towed graders, drags and labour-intensive methods for maintaining gravel roads. The study concluded that towed graders are capable of maintaining properly constructed gravel roads carrying up to 200 vehicles per day; that mechanical drags can temporarily improve the surface conditions of many gravel roads for periods of up to two months depending on the level of traffic, and that labour-intensive methods were found to be adequate for carrying out certain maintenance functions on gravel roads.

This report examines the cost-effectiveness of maintaining gravel roads using motor graders, towed graders and mechanical drags. The availability, utilisation and cost of using the different grading equipment is considered using data from Kenya and elsewhere in Africa. The results from studies to develop optimum grading frequencies for different countries are given and, finally, a method is recommended for managing the grading of unpaved roads for use in any country.

2 AVAILABILITY OF MAINTENANCE EQUIPMENT

The level of maintenance achieved on any road is mainly a function of the allocation or availability of staff, fuel and equipment. Of these three factors, it is often the availability of the equipment which limits the frequency of maintenance operations. For unpaved roads in developing countries, the motor grader is the most commonly used item of maintenance equipment. However, in these countries, motor graders tend to have a low level of availability, particularly when compared to other types of plant used in both construction and maintenance activities (Edmonds and De Veen 1982, Mason 1985, Ministry of Works and Supplies Malawi 1984). This is largely due to the complexity of the machine, inadequate mechanical maintenance, and almost complete reliance on imported spare parts.

2.1 KENYA

The Kenya Ministry of Transport and Communications (MOTC) estimated in 1982 and 1983 that their motor graders had a typical availability rate of 60 per cent. However, in the Kenya regravelling programme, in which part of this research study was incorporated, this figure was found to be over optimistic. In 1981, availability rates on the regravelling projects in Western and Nyanza Provinces were found to average 39 per cent for thirteen motor graders, eight of which were less than two years old. In the following year, the average had dropped to 31 per cent as shown in the following table:
TABLE 1

Motor grader availability in Kenya regravelling projects (per cent)

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Total No</th>
<th>1981</th>
<th>1982</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>8</td>
<td>38</td>
<td>25</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

Equipment records were not available for the other geographical areas utilised in the study, but availability of motor graders elsewhere was unlikely to have been better than the above rates. It should be noted that all of the regravelling projects had good experienced mechanical superintendents who were able to provide a high standard of plant maintenance. The main complaint of the superintendents was the inexperience of the plant operators and the lack of suitable spare parts. Many of the motor grader spares stocked at the various regravelling depots were items seldom required for field operations.

There are currently over 100 motor tractors in use with the MOTC. These vary in size from 40 to 80 hp. Records are again sparse, but estimates of availability from regional mechanical depots range from 60–80 per cent. In addition, some 90 tractors, nominally 48 hp, are utilised by the Rural Access Roads Programme (RARP). Since December 1981, the RARP have kept detailed records of plant availability, some of which are shown in the following table which gives availability and utilisation rates for a six to eight month period.

Even if the exceptionally high rates at West Pokot are excluded, the average availability is still over 65 per cent.

2.2 ELSEWHERE IN AFRICA

The TRRL study in Ghana found that motor graders were only available for 10 per cent of the time compared with 30 per cent for agricultural tractors utilised by the same organisation (Roberts and Gaituah 1983). These figures are particularly low, even allowing for the conditions generally met in developing countries. More typical levels of availability found elsewhere are 30 and 60 per cent respectively (Edmonds and De Veen 1982, Petts 1982, UNIDO 1983). In general, the higher figures are obtained by contractors, whilst government agencies normally have lower levels of availability, some substantially lower (UNIDO 1983).

In 1982, the International Labour Office (ILO) produced a list of availability and utilisation rates in ten African countries (Edmonds and De Veen 1982) for different items of equipment used on road maintenance operations. The rates quoted for availability of motor graders and large agricultural tractors were approximately 50 and 60 per cent respectively. The reason given for the relatively high level of grader availability was that, in a number of the countries, the equipment was new. However, the report suggested that, if a thorough analysis was carried out over a longer period, the figure would be lower.

Generally, records of equipment availability in developing countries are poor and rates are often based on theoretical estimates rather than on equipment records. For example, one country reports annual availability of 1824 hours for motor graders (Mason 1985). This is equivalent to over 7 hours per day for 250 working days a year which is essentially 100 per cent availability, which is highly unlikely. In personal communications, service managers of motor grader suppliers in Kenya, Zimbabwe and Botswana suggested that the figures quoted in the ILO report for motor graders were higher than that which would normally be met in practice in developing countries, with the exception of new equipment or equipment working under ideal conditions.

TABLE 2

Tractor availability in the Rural Access Road Programme

<table>
<thead>
<tr>
<th>Unit</th>
<th>Working Days</th>
<th>Days available</th>
<th>Days worked</th>
<th>Availability (per cent)</th>
<th>Utilisation (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kwale 1</td>
<td>120</td>
<td>55</td>
<td>50</td>
<td>46</td>
<td>42</td>
</tr>
<tr>
<td>Kwale 2</td>
<td>138</td>
<td>78</td>
<td>38</td>
<td>60</td>
<td>28</td>
</tr>
<tr>
<td>Embu 1</td>
<td>108</td>
<td>98</td>
<td>49</td>
<td>67</td>
<td>45</td>
</tr>
<tr>
<td>Embu 2</td>
<td>108</td>
<td>72</td>
<td>51</td>
<td>78</td>
<td>47</td>
</tr>
<tr>
<td>Uasin Gishu 1</td>
<td>156</td>
<td>90</td>
<td>32</td>
<td>58</td>
<td>21</td>
</tr>
<tr>
<td>Uasin Gishu 2</td>
<td>156</td>
<td>97</td>
<td>75</td>
<td>62</td>
<td>48</td>
</tr>
<tr>
<td>West Pokot 1</td>
<td>156</td>
<td>130</td>
<td>41</td>
<td>83</td>
<td>26</td>
</tr>
<tr>
<td>West Pokot 2</td>
<td>156</td>
<td>130</td>
<td>34</td>
<td>83</td>
<td>22</td>
</tr>
<tr>
<td>Average</td>
<td>127</td>
<td>92</td>
<td>53</td>
<td>72</td>
<td>35</td>
</tr>
</tbody>
</table>
The availability of any item of plant in developing countries is affected considerably by the availability of the spare parts. Major problems that occur with motor graders usually involve the hydraulics, clutch or transmission systems which are complex and difficult to correct. The problems are exacerbated as often few of the appropriate spares are stocked because of their high cost. Even on projects utilising new equipment, there are often insufficient or inappropriate spares supplied. The importation of spare parts usually involves foreign exchange and this frequently introduces delays in procurement. Repairs to motor tractors, however, are usually more straightforward, being mostly associated with difficult starting or contaminated fuel. In the case of the tractor/towed grader units, not only are spare parts more interchangeable with motor tractors but, because of the size of the agricultural industry in most developing countries, parts are more commonly available. Towed grader performance, particularly in Zimbabwe where over 300 are in use, but also in Zambia and Malawi, shows that their availability is over 90 per cent and spare parts do not present a significant problem. Tractors and towed graders also require a lower level of mechanical expertise than motor graders for both minor repairs and overhauls.

3 COSTS OF GRAVEL ROAD MAINTENANCE

The operating cost of grading equipment will have a significant effect on the cost of gravel road maintenance. Table 3 gives typical operating costs per hour for a motor grader, tractor/towed grader combination and a tractor/mechanical drag unit. The detailed calculations from which the table was constructed are given in Appendix A. All costs are based on January 1984 figures and, although they are Kenyan in origin, they will be typical of costs in many African countries. The main difference that may occur are local costs of fuel and tyres.

The condition of the gravel road surface dictates how many passes of the grader are required for each maintenance operation. Some countries stipulate a minimum of 5 passes in their design manuals. In practice, the poor initial condition of the road makes more passes necessary. This situation is due to the low availability of motor graders and other factors making maintenance infrequent. Assuming 5 passes, then it follows that, at an average speed of 2 kilometres per hour, it will require 5 hours of continual operation to complete 2 kilometres. Normal daily working periods are 8 hours, but the available time for grading each day is unlikely to be greater than 5 hours taking into consideration travelling to site, refuelling and downtime. Therefore, the output of the motor grader is estimated at 2 kilometres per day. This is confirmed by the Kenyan MOTC who, in 1984, calculated that their motor graders’ output was of this order. Therefore, actual daily costs to grade 2 kilometres of road are as follows:

TABLE 3

<table>
<thead>
<tr>
<th>Item</th>
<th>Motor Grader Costs/hr ($US)</th>
<th>% total costs</th>
<th>Tractor/towed grader Costs/hr ($US)</th>
<th>% total costs</th>
<th>Tractor/drag unit Costs/hr ($US)</th>
<th>% total costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depreciation</td>
<td>12.65</td>
<td>36</td>
<td>1.88</td>
<td>20</td>
<td>1.44</td>
<td>20</td>
</tr>
<tr>
<td>Interest</td>
<td>6.96</td>
<td>20</td>
<td>0.75</td>
<td>8</td>
<td>0.51</td>
<td>7</td>
</tr>
<tr>
<td>Fixed costs</td>
<td>19.61</td>
<td>56</td>
<td>2.63</td>
<td>28</td>
<td>1.95</td>
<td>27</td>
</tr>
<tr>
<td>Fuel</td>
<td>5.56</td>
<td>16</td>
<td>1.74</td>
<td>18</td>
<td>1.74</td>
<td>24</td>
</tr>
<tr>
<td>Lubrication</td>
<td>0.42</td>
<td>1</td>
<td>0.17</td>
<td>2</td>
<td>0.14</td>
<td>2</td>
</tr>
<tr>
<td>Tyres</td>
<td>1.62</td>
<td>5</td>
<td>0.34</td>
<td>4</td>
<td>0.27</td>
<td>4</td>
</tr>
<tr>
<td>Maintenance</td>
<td>4.40</td>
<td>12</td>
<td>1.57</td>
<td>17</td>
<td>1.52</td>
<td>20</td>
</tr>
<tr>
<td>Cutting edges</td>
<td>0.73</td>
<td>2</td>
<td>0.22</td>
<td>2</td>
<td>0.35</td>
<td>5</td>
</tr>
<tr>
<td>Operators/salaries</td>
<td>2.70</td>
<td>8</td>
<td>2.70</td>
<td>29</td>
<td>1.35</td>
<td>18</td>
</tr>
<tr>
<td>Running costs</td>
<td>15.43</td>
<td>44</td>
<td>6.74</td>
<td>72</td>
<td>5.37</td>
<td>73</td>
</tr>
<tr>
<td>Total costs</td>
<td>35.04</td>
<td>9.37</td>
<td>7.32</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
the costs of maintaining a kilometre of road with these units will be:—

\[ 8 \times \$9.37 = \$75 \text{ per kilometre}. \]

However, the availability of a motor grader in Kenya is only 30 per cent whilst motor tractor availability is about 60 per cent. Therefore, despite the higher potential output of the motor grader, the same length of road network can be maintained in a given period by the same number of units of either equipment, but at a reduced cost of $65 per kilometre if the tractor/towed grader units are used. However, if the availability of motor graders is reduced from the figures assumed in Appendix A, the unit costs of operation will increase because of the need to reappportion depreciation and interest charges. Because of the larger capital costs of motor graders compared with tractor/towed grader units, the increase in hourly costs will also be larger, making tractor/towed grader units even more competitive. Thus, for maintaining a properly constructed road, the tractor/towed grader unit can be considered as an alternative to the motor grader. The output per unit is likely to be the same and the cost of operation is significantly less. However, towed grader units cannot be used to maintain badly deteriorated roads where a motor grader will still be needed.

This is not the case for the tractor/mechanical drag units which, although capable of reducing surface roughness, pot-hole depths and corrugations, will not restore the camber of the road. The standard of work achieved will also be lower. Therefore, tractor-drawn drags have not been directly compared to the other types of maintenance equipment.

In Kenya there are currently some 20 000 kilometres of engineered gravel roads. If maintenance strategies utilising tractor/towed grader units were adopted instead of motor graders, then for a grading frequency of twice a year and a cost saving of $65 per kilometre, over $US 2.5 million could be saved annually. It is also important to realise that, by using less complex equipment which is less reliant on imported spare parts and foreign exchange constraints, the desired maintenance is far more likely to be achieved.

4 OPTIMUM GRADING FREQUENCY

4.1 VEHICLE OPERATING COST

Over the life of a road, the cost of operating vehicles is normally several times the cost of the initial road construction. The cost of maintaining the road throughout its life is very small when compared with the vehicle operating cost. However, the effect of road maintenance on vehicle operating costs can be considerable. This is because maintenance reduces the surface roughness of the road which, in turn, affects the vehicle operating costs. Figure 1 shows the typical changes that can be expected in the cost of operating vehicles over the range of roughness values normally found on unpaved roads. Grading the road at regular intervals restores the surface to an acceptable level of roughness which reduces the vehicle operating cost. The effect of this is shown in Figure 2. The results shown in Figures 1 and 2 were obtained by the TRRL computer program for road investment appraisal RTIM2 (Parsley and Robinson 1982), using typical data from Kenya.

In practice, the frequency at which a road is graded depends on the appearance of major defects or complaints from the public. Grading is normally carried out at least once a year, but more frequent grading may be necessary depending on the traffic loading and the rainfall. A better way of determining maintenance frequencies would be to grade the road often enough to ensure levels of roughness that minimise the sum of vehicle operating cost and the cost of grading.

![Fig. 1 The influence of surface roughness on vehicle operating costs](image1)

![Fig. 2 The influence of different grading frequencies on vehicle operating costs](image2)
TRRL have carried out studies using the RTIM2 computer program using data from Kenya, Papua New Guinea and Thailand to determine what the optimum grading frequency is for typical roads in each of these countries.

4.2 COMPUTER ANALYSIS

Data were collected from the MOTC and from the project appraisal and evaluation of the Thuchi-Nkubu road in Kenya, from the Department of Works and Supply and the Department of Transport and Civil Aviation in Papua New Guinea, and from a variety of sources including the Department of Highways in Thailand. Several assumptions had to be made about the input data to the computer program, but the cases are believed to be typical of gravel roads in each country. Some of the key features of the data are given below.

For each country, computer analyses were carried out for a range of traffic levels and for different frequencies of grading to determine the maintenance and vehicle operating cost over a period of the road’s life.

4.3 RESULTS

Total transport cost, which consists of vehicle operating cost plus road maintenance cost, has been plotted against grading frequency for each of the three countries in Figure 3. For Kenya, costs are for a five year period whereas, for PNG and Thailand, costs are for a ten year period. All future costs have been discounted at 10 per cent.

For the higher traffic levels, distinct minima on the curves can be seen although, for the Kenya data, the minima are much flatter and less distinct than those for PNG and Thailand. At the lower traffic levels, no minima are found indicating that the optimum grading frequency is less than once per year. However, the deterioration relationships which are used in the RTIM2 model are not calibrated for the combination of low traffic levels and low grading frequencies shown. In these cases, climatic effects are underestimated. It would normally be recommended that roads are graded at least once a year, irrespective of traffic level, and that ideally this should be carried out at the onset of the rainy season (Jones 1984).

The optimum grading frequencies found in these studies have been plotted against traffic level in Figure 4. In this figure, a comparison is also shown with optimum grading frequencies for Bolivia derived from a study carried out by Butler (1985) and a further study in Thailand carried out by BCEOM (1981). The differences between the optimum frequencies in the different cases are significant and are due to the analyses being carried out for different

**TABLE 4**

Key data for RTIM2 computer analysis

<table>
<thead>
<tr>
<th>Traffic composition (per cent)</th>
<th>Kenya</th>
<th>Papua New Guinea</th>
<th>Thailand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars</td>
<td>20</td>
<td>8–12</td>
<td>36</td>
</tr>
<tr>
<td>Light goods</td>
<td>50</td>
<td>52–36</td>
<td>18</td>
</tr>
<tr>
<td>Trucks 1</td>
<td>20</td>
<td>30–44</td>
<td>16</td>
</tr>
<tr>
<td>Trucks 2</td>
<td>—</td>
<td>10–8</td>
<td>22</td>
</tr>
<tr>
<td>Buses</td>
<td>10</td>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traffic growth (per cent)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars</td>
<td>5</td>
<td>4</td>
<td>4.7</td>
</tr>
<tr>
<td>Light goods</td>
<td>5</td>
<td>4</td>
<td>6.1</td>
</tr>
<tr>
<td>Trucks 1</td>
<td>5</td>
<td>4</td>
<td>6.1</td>
</tr>
<tr>
<td>Trucks 2</td>
<td>—</td>
<td>4</td>
<td>6.1</td>
</tr>
<tr>
<td>Buses</td>
<td>5</td>
<td></td>
<td>4.7</td>
</tr>
</tbody>
</table>

| Annual rainfall (mm)          | 1200  | 3500              | 1500     |
| Road width (m)                | 4.5   | 6.0               | 5.0      |
| Gravel type                   | Laterite | Coronus (coral)   | Laterite |
| Roughness after grading (m/km)| 3.5   | 6.5               | 3.5      |
material types, roughness levels, climate, traffic categories and unit costs. This illustrates the problem of applying conclusions drawn in one country to conditions in another country or even to a different road in the same country. However, the optimum grading frequencies found are not affected by the choice of discount rate used in the analyses. This is because the costs of maintenance and vehicle operation are both incurred at a uniform rate throughout the analysis period.

The effect of traffic composition on vehicle operating costs is illustrated in Figure 5. At the same traffic level, there is a significant change in operating costs depending on the percentage of trucks in the traffic stream. This will also affect the optimum grading frequency.

Analyses were also carried out to determine the effect on optimum grading frequency of using tractor/towed grader units instead of motor graders in Kenya. The results are illustrated in Figure 6. The use of towed graders reduces the total transportation cost but, because the cost of maintenance is small compared with the vehicle operating cost, very similar total transportation cost curves are obtained. The optimum grading frequency remains the same.

5 MANAGEMENT OF RECURRENT MAINTENANCE

5.1 GRADING

In the original version of Overseas Road Note 1 (TRRL Overseas Unit 1981), it was recommended
that grading should be carried out in response to the appearance of the defects of rutting, corrugations, pot-holes or defective camber. However, it is now recognised that because of the fairly rapid rate of deterioration of unpaved roads, it is unrealistic to plan their recurrent maintenance as a response to the appearance of defects. It is now recommended that optimum grading frequencies are determined appropriate to local conditions, and recurrent maintenance at this frequency carried out on a programmed basis.

An appropriate frequency of grading needs to be determined for each individual road. The frequency needed will depend on the material type and size, the traffic, climate, topography and other physical features, and should be chosen to keep the road in as near to the optimum economic condition as possible. Initial frequencies of grading should be determined by carrying out economic studies using a road investment model such as those developed by the World Bank (Watanatada 1985) and the TRRL (Parsley and Robinson 1982).

The appropriate level of maintenance should be determined in terms of the whole-life costing of the road. The investment model can be used to search for that frequency of maintenance that minimises the sum of maintenance cost and road user cost over the road’s life. The optimum value of maintenance derived will be different for roads in different areas and for roads carrying different levels of traffic or built with different materials.

The recommended optimum grading frequencies should be implemented in the field and a monitoring system should then be established which can be linked to a maintenance management system (PTRC 1985). A representative sample of unpaved roads should then be monitored for a period of at least one year and measurements taken of riding quality (roughness) and rut depth immediately before and after each maintenance grading carried out at the prescribed frequency. Traffic levels on these roads should also be monitored.

Modifications to the grading frequencies can then be made to ensure that the mean values of roughness and rut depth are such that the sum of road maintenance and road user cost is minimised. In this way, by the end of the year, grading frequencies will have been obtained that are calibrated for local conditions in such a way that they are close to optimum. A sample of the road network should have its performance monitored on a continuing basis to ensure that the grading frequencies being used are still keeping the roads in a condition that is close to the optimum. Any adjustments can then be made to the grading frequencies that prove necessary.

It is recognised that such an approach cannot take into account all the inhomogeneities that occur along a length of unpaved road, but the approach recommended provides a first step in developing a rational method of determining an optimum frequency.

5.2 ROUGHNESS

Measurements of roughness will normally be measured with a ‘response-type’ instrument and it will be necessary to calibrate this to ensure that the results obtained are consistent with the standard values used for vehicle operating cost calculations in the road investment models. Equations now exist (Sayers 1986) for relating standard roughness values to the absolute longitudinal profile of the road. The response-type instruments used can be calibrated by running them over roads with various levels of roughness. The longitudinal profile can be determined by measuring the road with a rod and engineer’s level. However, this method is laborious and the calculations needed to determine the calibrated values are time consuming. An instrument has been developed at TRRL for calibrating response-type roughness measuring devices more easily and this is known as the ‘Abay beam’. This contains an on-board microprocessor and, when the machine is used on the road, an automatic readout of calibration roughness is obtained.

5.3 DEFAULT GRADING FREQUENCIES

Many maintenance engineers working in developing countries will not have access to the computer
methods and roughness measuring equipment that are necessary to determine optimum grading frequencies in the way that has been recommended. An attempt has therefore been made to develop a simple grading frequency chart that can be used in these cases.

Figure 4 compares the grading frequencies that have been recommended for Bolivia, Kenya, Papua New Guinea and Thailand. The results of the two studies from Thailand suggest very different grading frequencies and this is surprising. The TRRL curve appears to give very much lower frequencies than any of the other studies and the reason for this is unclear. Data for this study was collected from a variety of different sources and it may be that this led to some incompatibility and unreliability. If this data set is excluded, then it is possible to plot an approximate envelope of grading frequencies such as that shown in Figure 7. This is not a statistical fit, but is based on handfitting to give whole numbers of grading per year for traffic flows of 50, 100, 150, 200 and 300 vehicles per day.

Thus when maintenance engineers do not have access to computer methods of determining grading frequencies, the chart given in Figure 7 can be used. Normally, grading frequencies should be chosen based on the mean line on this chart. Increasing grading frequencies about this will provide an increased level of service to road users and a lower level will be provided if grading frequencies are reduced. Grading according to the frequencies in this chart will enable a similar level of service to be provided on all roads in a network.

### 5.4 DRAGGING

Dragging should be used in areas where either loose material lies on the road or where materials tend to corrugate. Particularly in areas where corrugations tend to form, the frequency of dragging necessary is likely to be of the order of a few days. The present generation of road investment models are not calibrated for roads that corrugate, so the frequency of dragging cannot be determined using economic criteria. The actual frequency must be determined by carrying out simple experiments of the dragging requirement needed to stop the formation of corrugations. This frequency will vary for different material types, traffic levels and in different areas. As for grading frequencies, the effectiveness of the adopted maintenance frequencies must be monitored over time to ensure that the roads are still being kept in an appropriate condition. Dragging frequencies should be modified if that proves necessary.

### 5.5 PLANT REQUIREMENTS

If these methods are used to determine grading and dragging frequencies, it will be possible to determine the maintenance plant requirements for any given road network. In determining these requirements, a realistic assessment of plant availability and utilisation must be made, and this will require careful data analysis and study.

### 6 DISCUSSION

Costs have been determined for the maintenance of unpaved roads using motor graders, tractor/towed graders and tractor/mechanical drags, and this has highlighted the cost-effectiveness of using tractor/towed grader combinations for the maintenance of properly constructed roads which are not badly deteriorated. The poor levels of equipment availability in many developing countries has been highlighted and the effect that this has on the cost of maintenance determined.

A method has been outlined for determining optimum grading frequencies for roads using computerised investment models and this has been included in a recommended management method for recurrent maintenance. A grading frequency chart has been provided for use by maintenance engineers who do not have access to computer methods. It is recognised that the approaches recommended cannot take into account all the inhomogeneities that occur along a length of unpaved road, but they provide a first step in developing a rational method of determining optimum grading frequencies.

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APPENDIX A

OPERATING COSTS OF
MAINTENANCE EQUIPMENT

A major component of the cost of maintenance
activities is the operating cost of the equipment
involved. This appendix determines the relative
operating costs in Kenya for three types of
maintenance unit used on gravel roads, and then
derives the cost of maintaining these roads on a per
kilometre basis. All costs are based on January 1985
figures and converted to US dollars in the main text
at a rate of Ksh 14.79 = $US 1.00.

A.1 MOTOR GRADER

Cost components

<table>
<thead>
<tr>
<th>Model type: Caterpillar 120G—</th>
<th>Capital Cost</th>
<th>Expected life</th>
<th>Annual usage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 871 000 Ksh</td>
<td>10 000 hours</td>
<td>1 000 hours</td>
</tr>
</tbody>
</table>

(a) Fixed Costs

Cost Ksh/hr

1. Depreciation = \( \frac{1 871 000}{10 000} \) = 187.10

2. Interest on capital committed over the period of
usage and assuming an interest rate of 10% per
annum. Using the formula recommended in
Caterpillar Handbook.

Where N is expected life in years = \( \frac{\text{expected life}}{\text{annual usage}} \)

\[ I = \frac{N+1}{2N} \times \text{delivery price} \times \frac{\text{annual interest} \times N}{\text{total hours}} \]

\[ I = \frac{11}{20} \times 1 871 000 \times \frac{0.1 \times 10}{10 000} = 102.91 \]

Total 291.01
(b) Running costs

3. Fuel using figures based on grading, idling and travelling for average conditions
   = 15 litres/hour @ 5.48 Ksh per litre
   Cost Ksh/hr 82.20

4. Lubricating oils/grease
   Rate of 0.30 litres/hour @ 20.50 Ksh per litre
   Cost Ksh/hr 6.15

5. Tyres (6 off)
   Tyre life = 4 500 hours
   Tyre price (imported; none locally made)
   = 18 000.00 Ksh
   Therefore: Cost per hour = 6 x \( \frac{18 000}{4 500} \) = 24.00

6. Maintenance/Repairs
   Based on Caterpillar (Kenya) figures and rates used by Kenyan Ministry of Transport and Kenya Ministry of Agriculture, with due allowance for low labour costs and high cost of spare parts
   Cost Ksh/hr 65.00

7. Cutting edges
   Cost of blades (6") = 2700.00 Ksh
   Assumed life = 500 hours
   Therefore: Cost/hour = \( \frac{2 700 \times 2}{500} \) = 10.80

8. Plant operators salary plus assistant
   Plant operator Grade D (top of scale) Assistant Grade B (top of scale) including leave/house allowance
   Cost Ksh/hr 40.00

Total costs/hour = 290.01 plus 228.15 = 518.16 Ksh

No residual life is assumed after 10 000 hours usage.

A.2 MOTOR TRACTOR

Cost Components

Model type: International 533 (47 hp)---
Capital cost
Expected life
Annual usage

(a) Fixed costs

1. Depreciation
   \( \frac{147 000}{6 000} \) = 24.50

2. Interest using formula
   \( \frac{N + 1}{2N} \) x delivery price x interest rate x N
   \( \frac{11}{20} \) x 70 000 x 0.1 x 10 = 3.85

(b) Running costs

3. Fuel: model rated at 1.5 litres/hour/10hp/ max power
   Assume nominal \( \frac{1}{3} \) power for operation
   Fuel costs = \( 1 \times 4.7 \times 5.48 \) Ksh per litre
   Cost Ksh/hr 25.76

4. Lubricating oils/grease
   Rated 0.1 litres/hours @ 20.50 Ksh per litre
   Cost Ksh/hr 2.05

5. Tyres
   Cost 2 @ 3500.00 and 2 @ 2500.00 Ksh
   Therefore: Cost/hour = \( \frac{12 000}{3 000} \) = 4.00

6. Maintenance repair costs
   nominal method* = \( \frac{capital \ cost}{total \ hours} \)
   Cost/Ksh/hr 24.99

7. Plant operators salary
   Based on ‘C’ and ‘B’ scales respectively in Ministry of Transport job groups
   Cost Ksh/hr 20.00

Total = 109.87

Unlikely motor graders, tractors possess a residual value at the end of their working life. The National Institute for Agricultural Engineering use a figure of 15% for tractors in developing countries.

Therefore: Residual value = 0.15 x 147 000 = 22 050.00 Ksh

Values of depreciation, interest and maintenance/repairs will be reduced accordingly and are shown in brackets in the previous columns. This reduces the cost of operating a tractor of this type to 101.16 Ksh/hours.

A.3 TOWED GRADER

Cost components

Model type AG/4000---Capital cost
Expected life
Annual usage

(a) Fixed costs

1. Depreciation
   \( \frac{70 000}{10 000} \) = 7.00

2. Interest using formula
   \( \frac{N + 1}{2N} \) x delivery price x \( \frac{0.1 \times N}{total \ hours} \)
   \( \frac{11}{20} \) x 70 000 x \( \frac{0.1 \times 10}{10 000} \) = 3.85

(b) Running costs

3. Lubricating oils/greases
   Cost Ksh/hr 0.50

4. Tyres
   Current cost 1250.00 Ksh/tyre
   Expected life of 5 000 hours
   Therefore: Cost/hour = \( \frac{1 250}{5 000} \) = 1.00

* In practice firms use between 0.9 and 1.2.
  eg. Tate and Lyle use 1.02 for maintenance equipment on their estate roads in Africa.
5. Cutting edges
Current cost = 3200.00 Ksh
Expected life = 1000 hours
\[
\text{Cost/hour} = \frac{3200}{1000} = 3.20 \text{ Ksh/hr}
\]

6. Repairs/maintenance (based on Zimbabwe data)

7. Plant operator's salary (Based on 'C' Scale Kenya Ministry of Transport job group)

Total 37.55

No residual value after 10,000 hours usage.

A.4 MECHANICAL DRAG

Cost components
(Metal framed drag)—Capital cost 5000 Ksh
Expected life 10000 hours
Annual usage 1000 hours

(a) Fixed costs

1. Depreciation = \[\frac{5000}{10000}\] = 0.50 Ksh/hr

2. Interest = \[\frac{11}{20} \times \frac{5000 \times 0.1 \times 10}{10000}\] = 0.28 Ksh/hr

(b) Running costs

3. Maintenance/repairs = 1.20 Ksh/hr
Additional bolts/chains/structural repairs

4. Cutting edges
Cost of blades = 2600.00 Ksh
Assumed life 1000 hours
\[
\text{Cost/hr} = \frac{2600}{1000} = 5.20 \text{ Ksh/hr}
\]

Total 7.18