

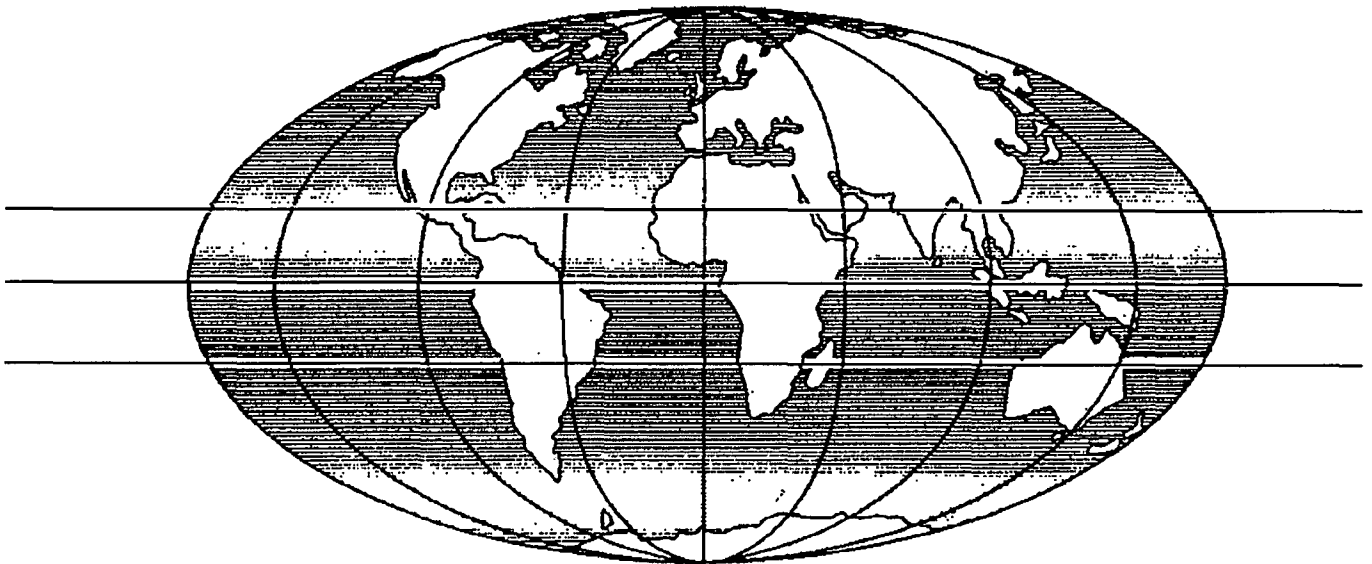


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TITLE Towed graders and tractor-based maintenance of low volume roads

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FIFTH INTERNATIONAL CONFERENCE ON LOW VOLUME ROADS

TOWED GRADERS AND TRACTOR-BASED MAINTENANCE OF LOW VOLUME ROADS

by

R C Petts* and T E Jones**

ABSTRACT

This paper reviews the historical development of equipment for constructing and maintaining the surface of earth and gravel roads. It focuses on the use of tractor-drawn graders and drags. The paper also develops the case for tractor-based road maintenance operations for these roads in developing countries, instead of the normal motor grader and truck based operations.

The paper suggests that for many secondary and tertiary road networks, routine and some periodic maintenance could be carried out using wheeled agricultural tractors as the sole power units towing mechanical graders, gravel haulage trailers, water bowsers and rollers as required. The operations could be supported by local labour for such activities as gravel excavation, loading and unloading, spreading and drainage maintenance.

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The road maintenance could be carried out by direct labour (force account) organisations or contracted out to the private sector. Contract agricultural work is already well established in many developing countries and road maintenance and improvement activities could extend the type of work carried out by tractor-owning contractors.

The paper shows how tractor-based road maintenance operations would be significantly cheaper in terms of capital and running costs. It also discusses why the logistic and support problems of such operations would be less than for current motor grader-based operations.

Tractor-based road maintenance operations would make more effective use of the limited financial and other resources available to road maintenance organisations in developing countries.

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1. INTRODUCTION

In many developing countries, the motorised grader is the principal equipment item for maintaining unpaved roads. However, the availability* of this equipment is very low due to inadequate funding resources, mainly for spare parts and maintenance facilities, and the shortage of the trained manpower required to maintain the equipment. This low level of availability has led, particularly in African countries, to inadequate maintenance operations on the majority of the unpaved road networks.(1).

Recent research suggests that for many secondary and tertiary road networks routine and some periodic maintenance could be carried out using wheeled agricultural tractors as the sole power units, towing mechanical graders, gravel haulage trailers, water bowsers and rollers as required. The operations could be supported by local labour for such activities as gravel excavation, loading and unloading, spreading and drainage maintenance. The maintenance could be carried out by direct labour (force account) organisations or contracted out to the private sector. Contract agricultural work is already well established in many developing countries and road maintenance and improvement activities could provide an extension to the type of work carried out by tractor-owning contractors.

*The terms availability and utilisation frequently used in the text refer to equipment which is available for maintenance works and is utilised in maintenance activities. Utilisation is expressed as a percentage of the time that the equipment is available for work.

The paper reviews the historical development of equipment for constructing and maintaining the surface of earth and gravel roads. It focuses on the use of tractor-drawn towed graders and drags. The paper also develops the case for tractor-based road maintenance operations for these roads in developing countries instead of the normal motor grader and truck-based operations.

2. HISTORICAL DEVELOPMENT

Tractor or vehicle-drawn graders have been used for grading the surfaces of unpaved roads at least since 1909 (see Plate 1). Initially, they had solid metal wheels and were normally drawn by tractors (see Plate 2) although some models were self propelled as in Plate 1. Very early graders often incorporated complicated mechanical devices for carrying out activities in addition to surface grading. These included the construction of mitre drains (turn outs), side drains and side slopes. See Figs 1 & 2. Early road construction techniques also included graders towed in tandem and the use of tractor-drawn trailers with side-tipping facilities for the transportation of gravel wearing course or fill material, see Plates 3 & 4. This type of road construction equipment was used quite extensively in most countries until the mid-thirties when the motorised grader was developed from a hybrid tractor fitted with a full width mouldboard see Plate 5.

In developing countries, particularly in the early fifties, the introduction of the motorised grader, often funded by developed countries or donor agencies, led to a decline in the use of tractor-towed grading equipment. Subsequently, high capital costs, operating costs and inadequate plant maintenance, coupled with foreign exchange constraints, particularly with

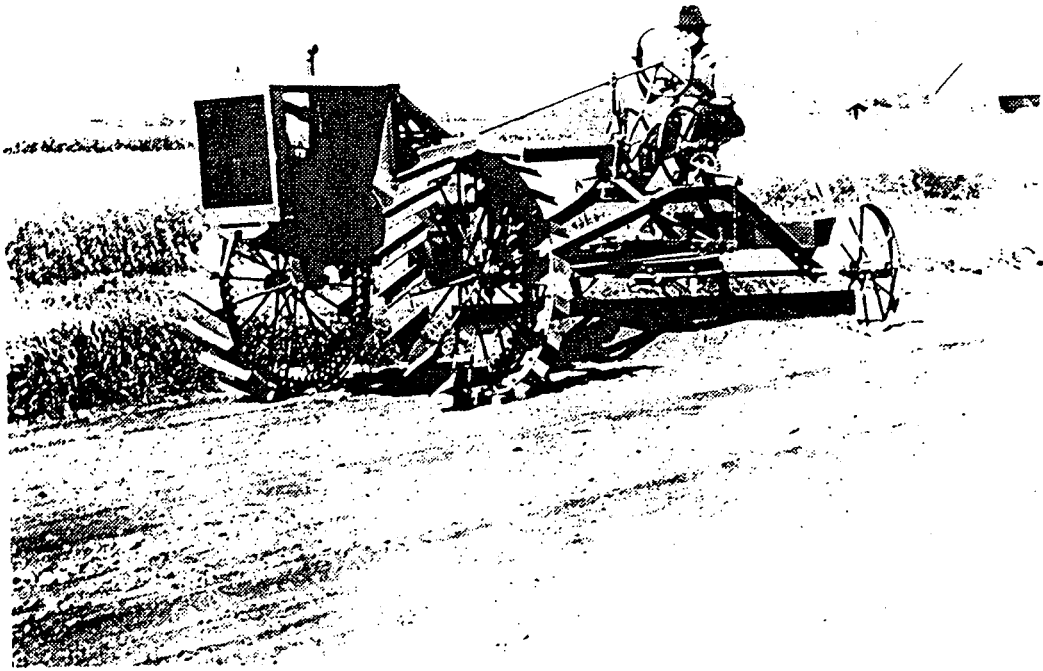


Plate 1 Self propelled grader (1919)

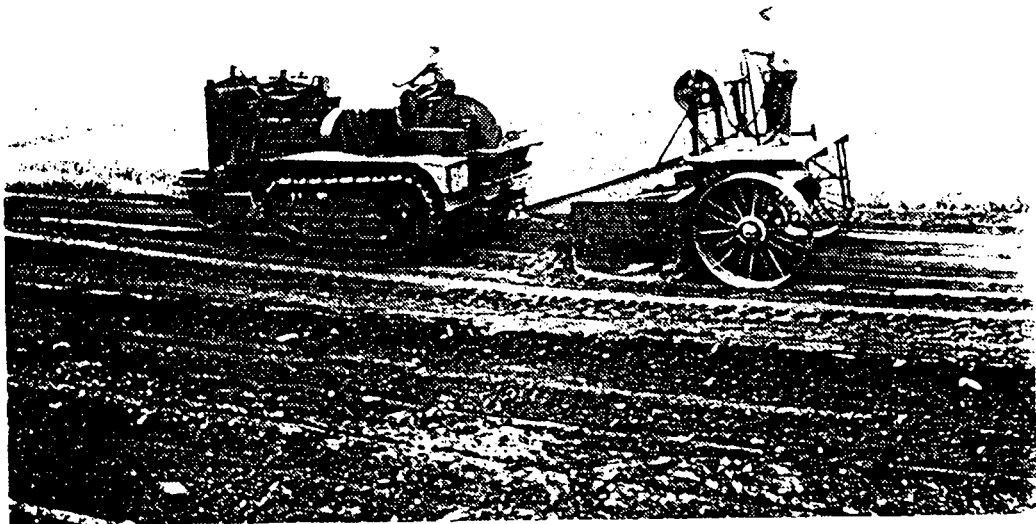


Plate 2 Road leveller (1919)

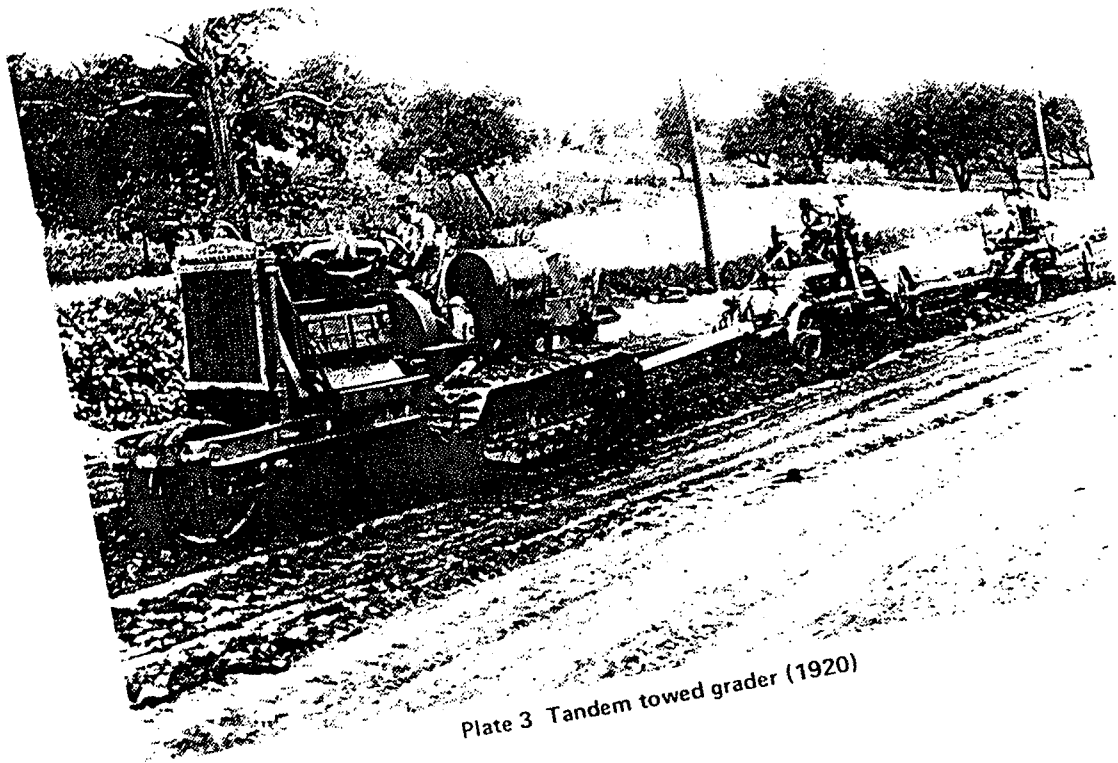


Plate 3 Tandem towed grader (1920)

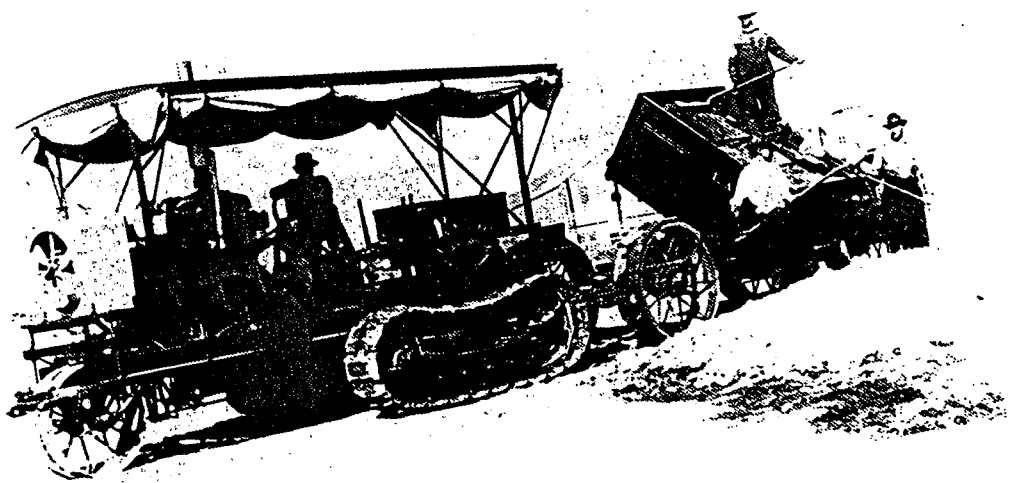


Plate 4 Early side tipping trailers

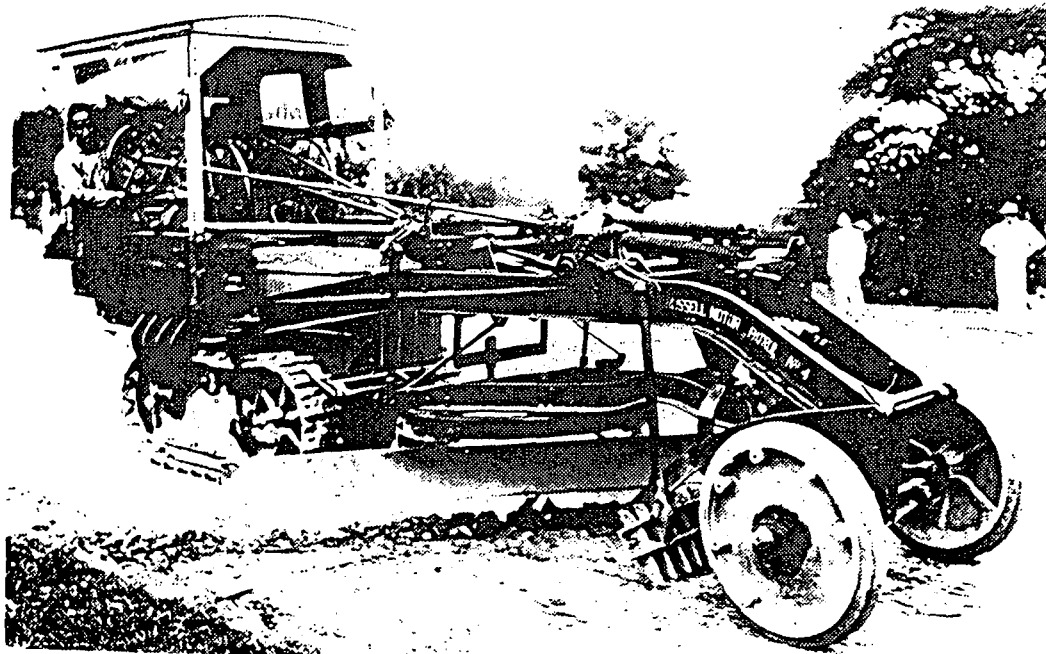


Plate 5 Prototype motorised grader (1926)

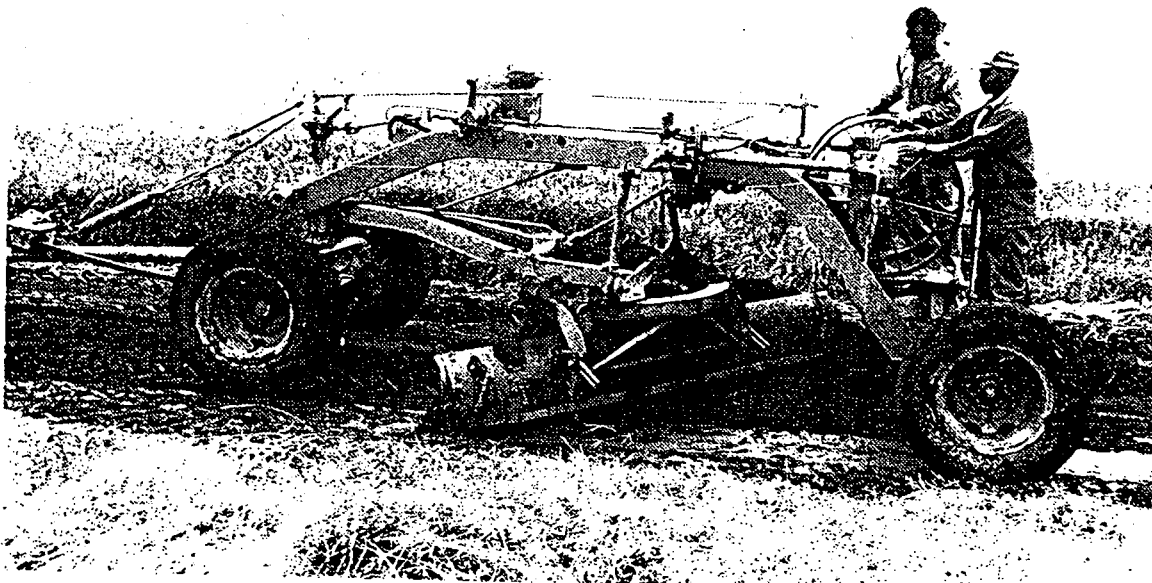


Plate 6 1960's type grader in use in Africa

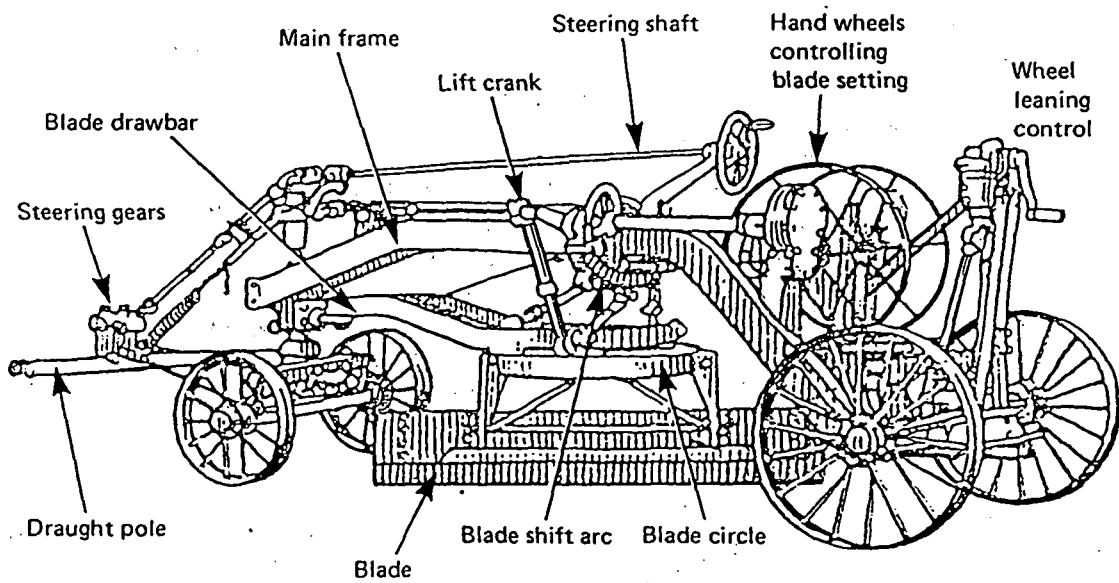
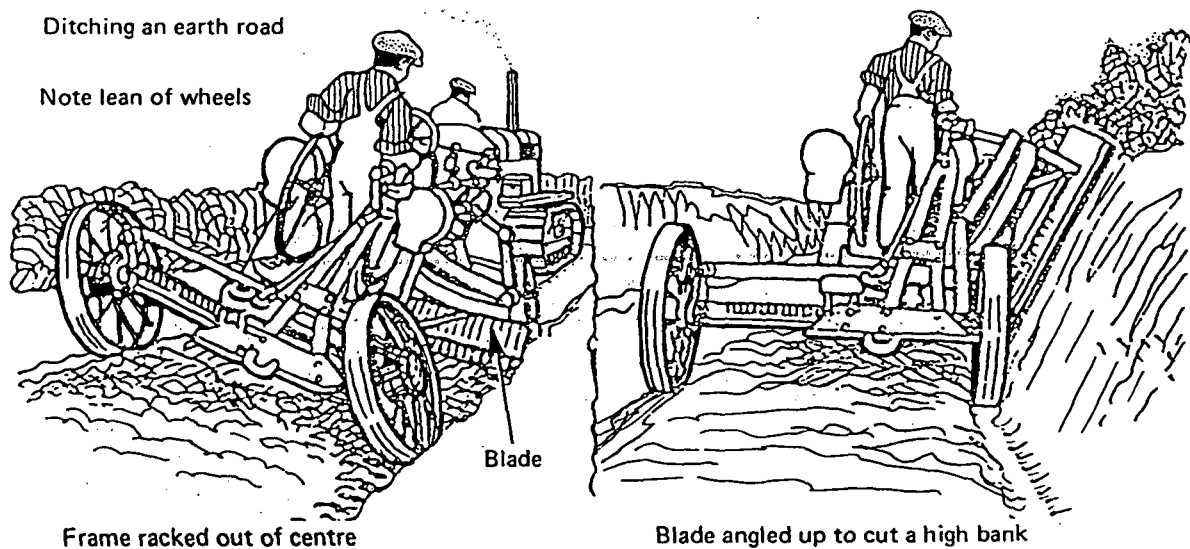


Fig.1 Basic towed grader (1920)



This type of Grader has a blade that can be set to any angle on either side to form road surfaces, ditches or banks. This one is tractor-hauled, but some are self-propelling

Fig. 2 Ditching and side slope techniques

regard to obtaining spare parts, has meant that the availability of motorised graders in developing countries has become problematic, resulting in extremely low availability of equipment. In many cases the end result is that road maintenance is simply not carried out, particularly on important and highly trafficked routes.

The low availability of maintenance equipment is one of the principal reasons for the poor condition of a substantial amount of the unpaved road networks in Africa (1). More recently this situation has led to countries looking at cheaper and more reliable alternatives. In the last twenty years a number of countries, particularly in Africa, have started to utilise tractor-towed graders for surface treatment of gravel roads, see Plate 6 and more recently tractor-towed compactors, water bowsers and trailers. Some countries are now exploring the feasibility of operating maintenance units based entirely on tractor-towed systems. One example is Thailand, where the Office of Accelerated Rural Development (ARD), which is responsible for the construction and maintenance of 19,000 kms of unpaved road, has already started to implement such a system. See Plates 7 & 8.

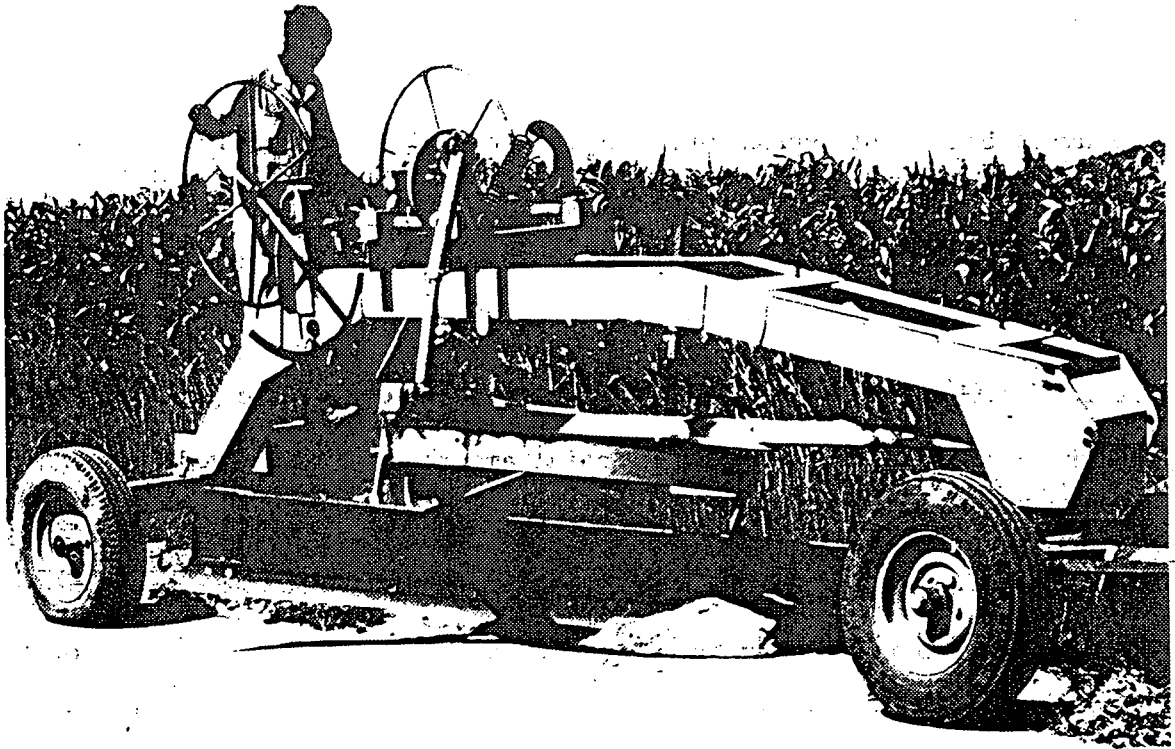


Plate 7 Towed grader currently
utilised in Thailand .

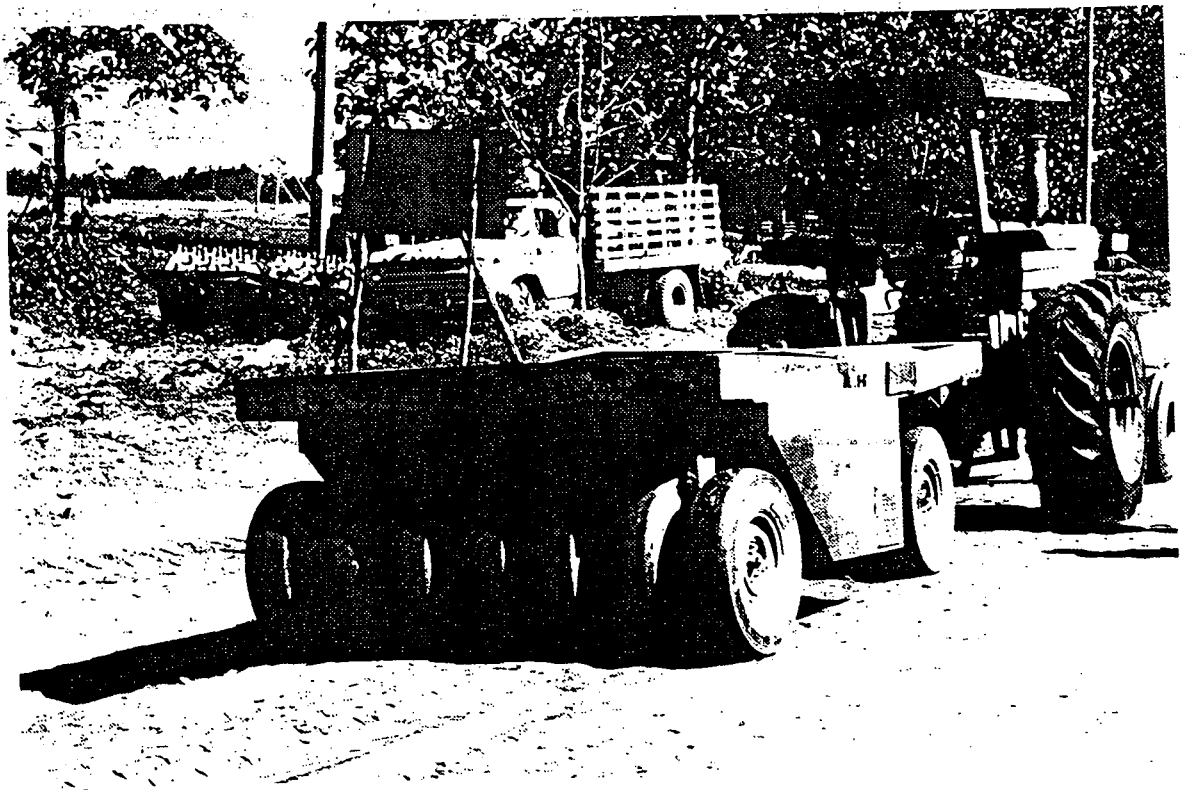


Plate 8 Tractor towed compactor

The principal arguments in support of such an approach are:

Motor graders, front-end loaders and dozers are expensive specialist items of equipment designed for use by medium and large contractors in developed countries with good workshop facilities, highly skilled operators and mechanics and readily available spares. They are unsuited to maintenance work in developing countries where the above conditions rarely exist and units usually operate at long distances from workshop facilities.

Conversely, agricultural tractors are mechanically simple, flexible enough to be used to tow different work tools, simple to operate, service and repair, cheap to purchase and operate, and spares are far more readily available than for the aforementioned specialist equipment. They are also within the purchasing capability of small local contractors.

Towed graders suitable for road maintenance are available from about 2 - 5 tonnes in weight and some models can be operated manually (without hydraulics). Therefore a tractor-based maintenance unit can function without any hydraulically-operated equipment, thus avoiding the breakdown, servicing and repair problems of such relatively complex equipment.

Motor graders typically have extremely low availability rates in developing countries. Tractor-based equipment can normally be expected to provide availability of 2 - 3 times that of the specialist equipment.

The development of mechanical drags for levelling unpaved roads has changed only slightly from the 1920s when the prime mover was a horse as shown in Fig 3. Early models of the drags illustrated in Figs 4-6 are basically the same as those used today in developing countries. They are effective in reducing surface irregularities on gravel roads and on low trafficked routes and are often the most appropriate solution. Current usage and models are discussed in detail elsewhere (2).

3. CURRENT PROBLEMS OF MOTOR GRADER-BASED ROAD MAINTENANCE IN DEVELOPING COUNTRIES

In many developing countries the principal item of routine maintenance equipment for earth and gravel roads is the motor grader. It is also sometimes used to reshape the unsealed shoulders of paved roads.

The motor grader is used for reshaping the running surface, removing corrugations and cleaning the side and mitre drains (turn-outs). The machines typically work alone, operating from a road camp base. Grader operations are usually supplemented by labour gangs also working from road camps.

Although the support operations are manual, a truck is usually required to transport the gang from the road camp to the worksite each day. Other specialist equipment such as bulldozers, front-end loaders and self-propelled rollers and bowlers are used for the provision of gravel surfacing. This is required for routine patching and periodic regravelling. Haulage is normally carried out using tipping trucks.

These equipment-based operations were set up before the global oil crises of the 1970's. Prior to these events, equipment was relatively cheap and road authorities in developing countries did not face the serious problems of procurement and equipment support that many of them face today.

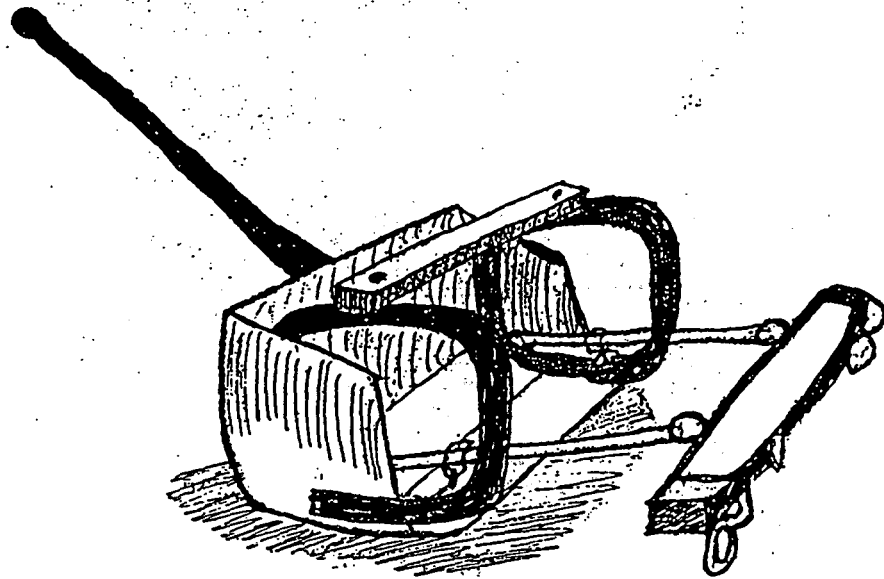


Fig.3 Horse drawn scraper

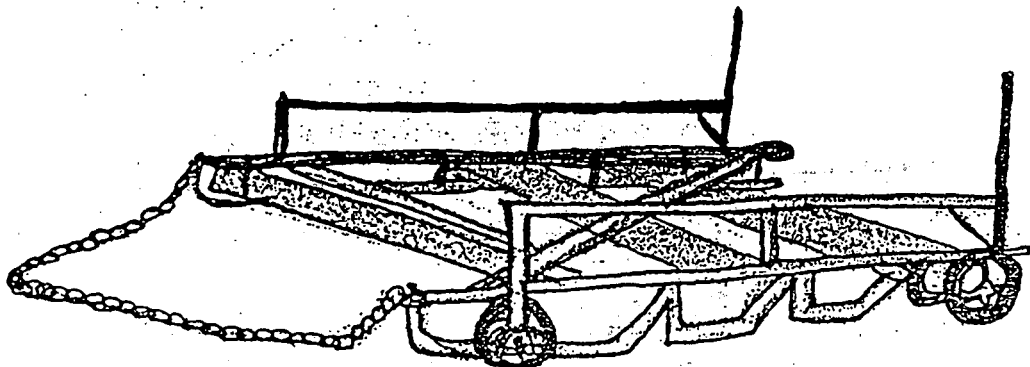


Fig.4 Two blade adjustable road drag

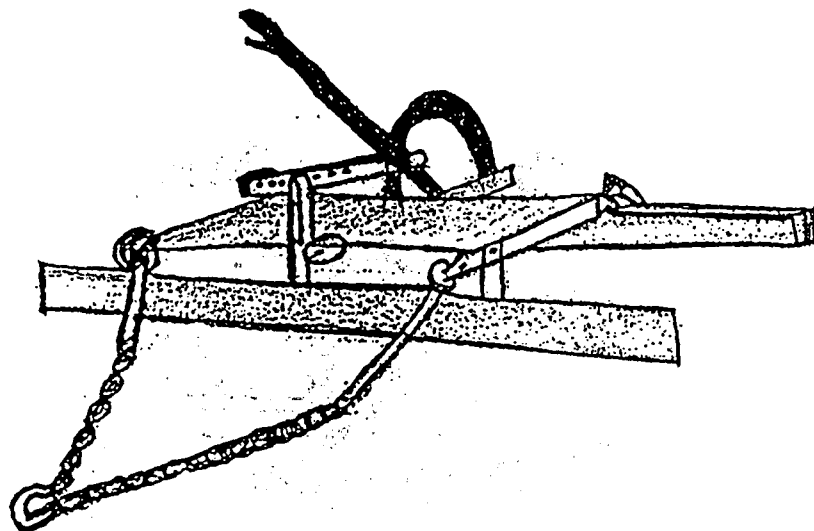


Fig.5 Road hone

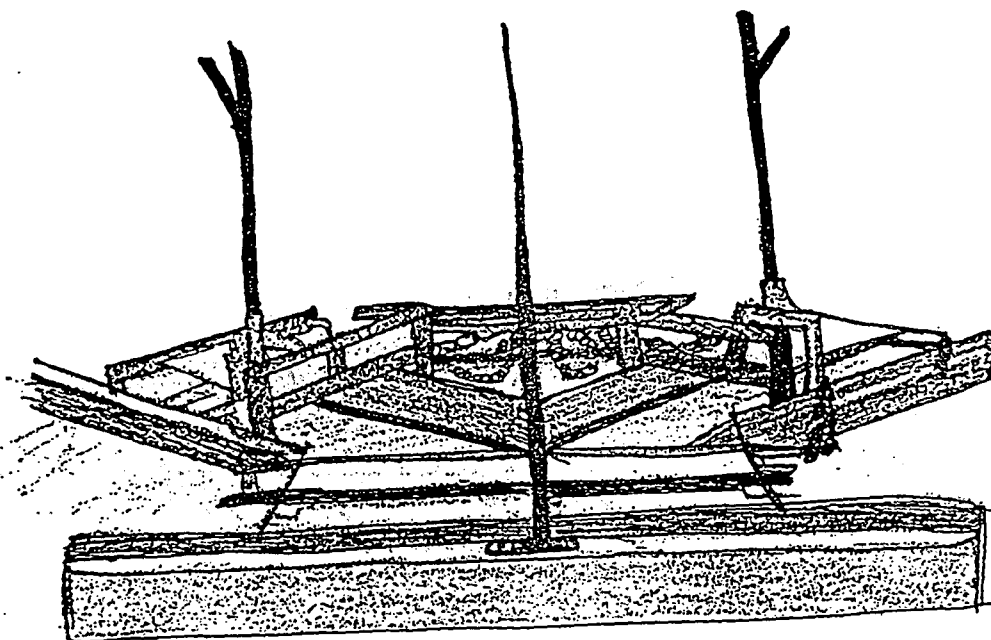


Fig.6 Three way road drag

The operating environment of road authorities has changed considerably over the last 20 years. Motor graders, front-end loaders and dozers are now expensive and specialist items of equipment, ideally suited for use by medium or large contractors in developed countries. These organisations are able to closely support their equipment on construction sites with good site workshops and mobile workshop facilities. Highly skilled mechanics and operators, readily available spares and technical support enable the full potential of the machines to be realised in these circumstances.

These conditions rarely exist in developing countries. Typical problems currently encountered by the road authorities include:

- Equipment working individually at long distances from workshop facilities.
- Poor workshop facilities. Mobile workshops rarely exist.
- Lack of the necessary trained workshop personnel able to manage or carry out the specialist servicing and repair work.
- Cumbersome procurement procedures for spare parts and replacement equipment.
- Wide variations in models and makes of equipment due to restrictive tendering (usually lowest initial cost) procedures. This exacerbates spares procurement and stocking problems.
- Foreign exchange shortages exist in many developing countries so that road authorities/equipment agents have difficulties in procuring equipment and spares from abroad. These organisations rarely get priority allocations of available foreign exchange, particularly for road maintenance equipment.
- The national fleets of the individual equipment models are relatively small so that it is uneconomic or impractical to maintain extensive spares stocks in a country, either with the road authority or the local equipment agents.
- A lack of appreciation of the true cost of operation of sophisticated imported equipment due to the "funds" accounting, rather than total cost accounting, systems used.
- Absence of effective management information systems.

- Lack of accountability or incentives to 'perform' in many road authorities.

With the above constraints it is not surprising that the road authorities cannot even approach the equipment availability rates achieved by developed country contractors. Instead of achieving rates of 60-70%, or more, availability (where reliable records exist) is typically of the order of 20% for road maintenance equipment(3). The cost of owning and operating equipment at these low rates is quite uneconomic as Table 1 shows.

TABLE 1 Illustration of the effect of utilisation on the operating costs of an item of equipment

Typical hourly costs for equipment (US\$)			
Actual annual utilisation (hours)	1000	500	250
% of working year	57	29	14
<u>Fixed costs</u>			
Interest, depreciation workshop and salaries	20	40	80
<u>Variable costs</u>			
Fuel, lubricants tyres, maintenance repairs cutting edges	15	15	15
Total hourly cost	35	55	95

Note: Working year calculated as 1750 hours ie 250 working days @ 7 hours

Interventions have been made with the assistance of various external agencies over recent years to try to counter the above mentioned constraints. Provision of new equipment, spares, workshops or training have often brought short term improvements in equipment performance. However the improvements have usually not been sustained, due to inability to provide a comprehensive solution to the range of influential factors.

It is necessary to radically rethink the approach to maintenance of unsurfaced roads in developing countries. Less reliance must be placed on the use of sophisticated, expensive, imported equipment. A new approach must be made that makes better use of the locally available technologies and resources.

4. THE ADVANTAGES OF TRACTOR-BASED OPERATIONS

Wheeled agricultural tractors are mechanically simple compared to conventional road maintenance equipment. However, units are now commonly available with power of up to 100 HP (75 kW) and above, with either two or four wheel drive. Tractors of 50 - 80 HP rating are adequate for hauling towed graders of about 2 tonnes mass for light grading. Heavier (4 tonne) towed graders usually require tractors of 80 - 100 HP range and 4 wheel driver configuration. These can be used for heavy grading.

Agricultural tractors are also widely available in developing countries. Table 2 shows details of annual sales of agricultural tractors in Kenya compared to the total fleet of motor graders in the country.

TABLE 2. Agricultural Tractors: National Sales (All Manufacturers)

	POWER RANGE (HP)				ALL
	40-50	50-80	80-110	>110	
1986	164	487	327	94	1072
1987	153	516	295	23	987
1988	325	404	318	46	1093
1989	242	529	351	66	1188
	884	1936	1291	229	4340

Source: Motor Trade Association

NOTE: 1 HP = 0.746 kw

Motor Graders: Estimated Total National Fleet: All Manufacturers.

	No
Ministry of Public Works	350
Other Organisations	150
<hr/>	
Estimated national fleet	500

The capital cost of a 4WD 100 HP tractor is typically about one quarter that of a 125 HP motor grader. Even including the cost of the towed grader unit the tractor combination is much less than half the price of the maintenance motor grader. Investment (interest on capital) costs are correspondingly lower.

The support and running costs for agricultural tractors and towed equipment are also significantly lower than for conventional road maintenance equipment.

The availability of any item of plant in developing countries is affected considerably by the availability of 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 often exacerbated as 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 allocation and this frequently introduces delays in procurement. Repairs to 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 200 are in use, and also in Zambia and Malawi shows that their availability is over 90 per cent and spare parts do not present a problem. Tractors and towed graders also require a lower level of expertise than motor graders for minor repairs and overhauls.

Adoption of agricultural tractors as the basic power source for maintenance grading operations also allows flexibility to carry out other maintenance tasks. In addition, the tractors can be used to tow gravel haulage trailers for regravelling. The Kenya Rural Access Roads and Minor Roads Programmes have used tractor-trailer combinations to haul gravel for the construction and periodic maintenance regravelling of a road network of over 9000 Kms. Operations are currently planned for expansion to a network of 12,500 Km (4).

Tractors can also tow rollers and water bowsers to achieve better compaction of gravel surfacing. Even workshop and labour accommodation could be towed in tandem with equipment between remote worksites to minimise mechanical support problems and avoid the need to return to base camp each evening. It would be possible to set up mobile maintenance units with 2 - 3 tractors based on the concept shown in Figure 8.

The tractor-based operations could be supported by local labour for such activities as drainage maintenance, gravel excavation, loading, unloading and spreading where appropriate.

An important consideration is that all of the attachments: towed graders, gravel haulage trailers, rollers, bowsers, workshop and mobile accommodation could be built and, therefore, easily maintained, in developing countries.

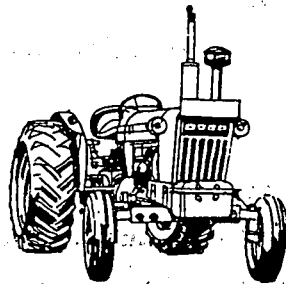
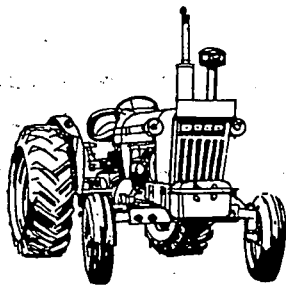
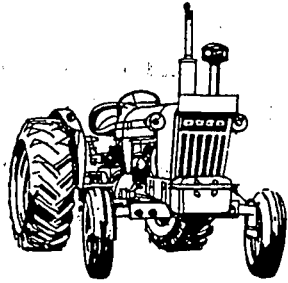
The low capital and running costs and ease of support of tractor-based equipment means that local contractors can be attracted to road maintenance activities using this type of equipment.

Road maintenance contracts could complement contract agricultural activities already established in many developing countries, particularly where the latter have a limited season.

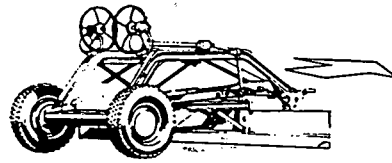
Mechanical equipment
Attachments options (no hydraulics)

Power source

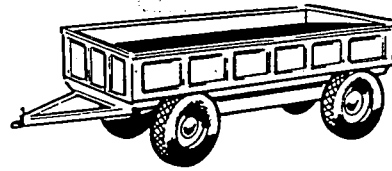
Agricultural tractors



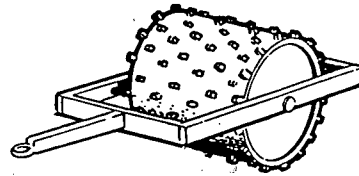
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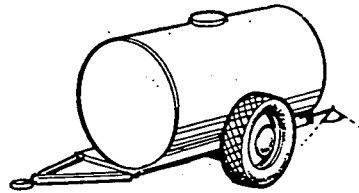
Towed graders



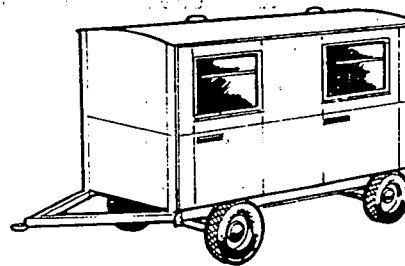
Haulage trailers



Rollers



Bowsers (fuel and water)



Mobile accommodation and workshop

Notes. Units can be towed in tandem between worksites
Number of each item according to maintenance requirements

Fig.8 Flexible technology

Suggested tractor based road maintenance unit resources

5. 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 (5)(6)(7). This is largely due to the complexity of the machine, inadequate mechanical maintenance and almost complete reliance on imported parts.

5.1 Kenya

The then Kenyan 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 Kenyan regravelling programme, 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 3. Motor Grader Availability in Kenyan Regravelling Projects (per cent)

MANUFACTURER	TOTAL No	1981	1982	Average
A	8	38	25	32
B	3	33	33	33
C	2	50	50	50

Equipment records were not available for the other geographical areas utilised in the study but availability of motor graders elsewhere are unlikely to have been better than the above rates. It should be noted that all of the regravelling projects had the expertise of 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.

At the same time there were over 100 motor tractors in use with the MOTC. These varied in size from 40 to 80 hp. Records are again sparse, but estimates of availability from regional mechanical depots ranged from 60-80 per cent. In addition, some 90 tractors, nominally 48 hp, were utilised by the Rural Access Roads Programme (RARP) for gravel haulage. Since December 1981, the RARP 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.

TABLE 4

Tractor Availability in the Rural Access Road Programme (1981/82)

Unit	Working Days	Days Available	Days Worked	Availability (per cent)	Utilisation (per cent)
Kwale 1	120	55	50	46	42
Kwale 2	138	38	38	60	28
Embu 1	108	84	49	67	45
Embu 2	108	72	51	78	47
Uasin Gishu 1	156	90	32	58	21
Uasin Gishu 2	156	97	75	62	48
W. Pokot 1	156	130	41	83	26
W. Pokot 2	156	140	34	83	22
AVERAGE	127	62	53	72	35

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

5.2 Elsewhere in Africa

The TRRL found in Ghana 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 (5). These figures are particularly low even allowing for the conditions generally met in developing countries. More

typical levels of availability found elsewhere are 50 and 60 per cent respectively (6). In general, the higher figures are obtained by contractors, whilst government agencies normally have lower levels of availability, some substantially lower (7).

In 1982, the International Labour Office (ILO) produced a list of availability and utilisation rates in ten African countries (6) 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, the World Bank reports annual availability of 1824 hours for motor graders (1). 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.

6. CURRENT USAGE OF TOWED GRADERS

6.1 Zimbabwe

Local manufacturers in Zimbabwe currently fabricate a 2 tonne mass towed grader, with a total production of over 500 to date since 1960. Of these some 200 are currently utilised in Zimbabwe by the three authorities responsible for gravel roads. These are the Ministry of Transport, the Association of Rural Councils and the District Development Fund. A number of other African countries namely Malawi, Zambia and, to a lesser extent, Ghana, Tanzania and Kenya also use the Zimbabwe manufactured grader which is normally towed with a 50 hp agricultural tractor. They are generally used for

maintaining gravel roads with traffic volumes of up to 200 vehicles per day but are also used in Zimbabwe for light construction activities. These towed graders have proved to be extremely reliable with a minimal requirement for spare parts. The experience of Zimbabwean authorities and those of other countries in Southern and Central Africa means that this type of grader will be in continuous use for some time.

6.2 Thailand

The office of Accelerated Rural Development in Thailand, which is responsible for the construction and maintenance of 19,000 kilometres of rural roads, is currently using the Zimbabwe towed graders on an experimental basis. If their performance is found to be acceptable then almost certainly the towed grader will be manufactured locally. There were some minor problems initially in Thailand related to the physical effort required to operate the graders but these have been overcome with the use of more efficient gearing for the controls. The experimental study in Thailand indicates that the performance of the towed grader in reducing surface roughness is similar to that achieved using the motorised graders.

6.3 Kenya

Although the 2 tonne Zimbabwean grader provides a satisfactory performance, some engineers feel that an increase in weight would make it more adaptable for construction purposes and for maintaining heavy clay soils or coarse gravels eg volcanic and cinder materials. In Kenya, a local manufacturer is currently producing a heavier towed grader of approximately 4 tonnes mass. These are fully-trailed units with greater load transfer on to the tractor driving wheels, whilst the longer distance between the hitch point and rear wheels ensures a more even grade. See Plates 9 and 10.



Plate 9 Prototype heavy grader on trial near Nairobi

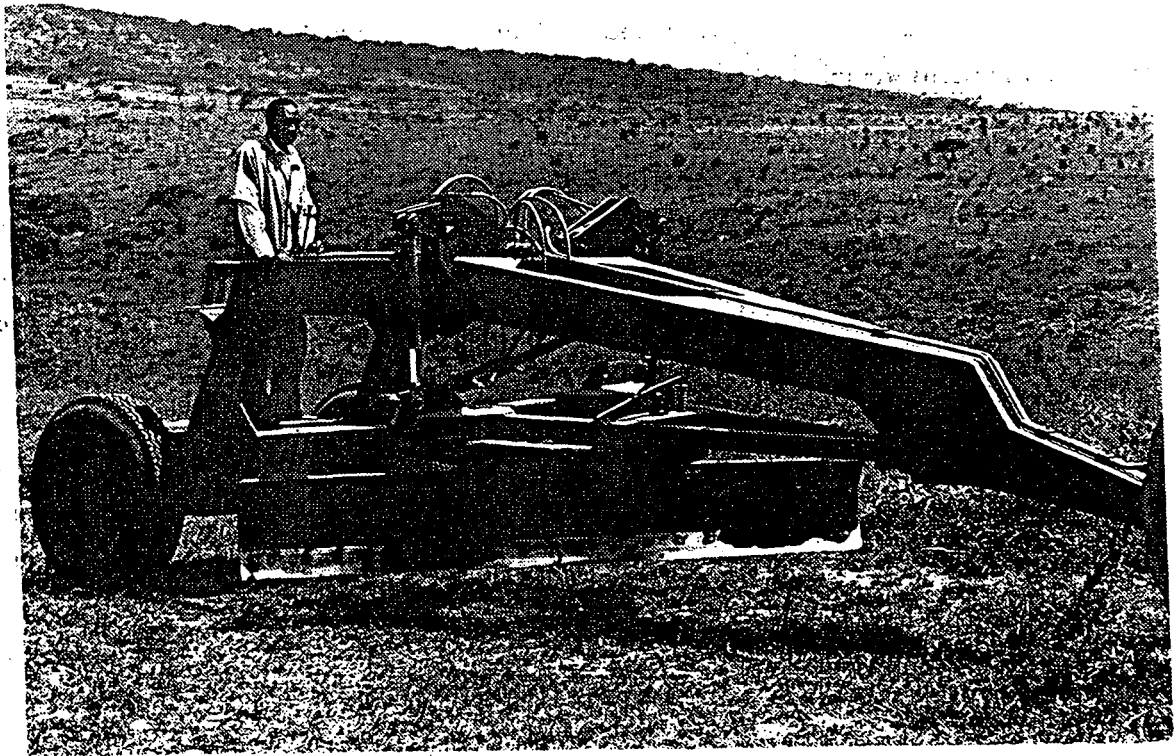


Plate 10 Prototype heavy grader on trial on clay soils

6.4 Elsewhere

In the UK towed graders are available but they are normally only utilised for light grading eg on sports grounds. These are the Hallam and Simba graders. They have been used overseas but the main drawback is that their design is more appropriate for developed country circumstances which could result in problems similar to those associated with the motor graders in developing countries ie foreign exchange constraints on imported spare parts.

Feedback from many engineers responsible for the maintenance of rural roads in developing countries highlights the real need for alternatives to the motorised grader for reducing surface roughness and restoring camber. The development of the Zimbabwean or Kenyan towed grader should provide the solution.

7. COSTS OF GRAVEL ROAD MAINTENANCE

The operating cost of grading equipment will have a significant effect on the cost of gravel road maintenance. Table 5 gives typical operating costs per hour for a motor grader and tractor/towed grader combination. All costs are based on January 1987 figures and although they are Kenyan in origin they will be typical of costs in many African countries. The main differences that may occur are the local costs of labour, 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 operation 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, it then 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:-

8hrs @ US\$ 45.55 = US\$ 364
ie US\$ 182 per kilometre

TABLE 5 Hourly Operating Costs of Maintenance Equipment (1987)

Item	Motor Grader		Tractor/towed grader		Tractor/drag unit	
	Costs/hr (US\$)	% total costs	Costs/hr (US\$)	% total costs	Costs/hr (US\$)	% total costs
Depreciation	16.45	46.80	2.45	26.00	1.87	26.00
Interest	9.05	26.00	0.98	10.40	0.66	9.10
Fixed costs	25.49	72.80	3.42	36.40	2.54	35.10
Fuel	7.23	20.80	2.26	23.40	2.26	31.20
Lubrication	0.55	1.30	0.22	2.60	0.18	2.60
Tyres	2.11	6.50	0.44	5.20	0.35	5.20
Maintenance	5.72	15.60	2.04	22.10	1.98	26.00
Cutting edges	0.95	2.60	0.29	2.60	0.46	6.50
Operators/salaries	3.51	10.40	3.51	3.70	1.76	23.40
Running costs	20.06	57.20	8.76	93.60	6.98	94.90
Total costs	45.55		12.18		9.52	

One of the results of the TRRL study in Kenya showed that a tractor-towed light grader unit could maintain approximately one kilometre of road per day. The unit requires 8 hours of operating time, so the costs of maintaining a kilometre of road with these units will be:-

8hrs @ US\$ 12.18 = US\$ 97 per kilometre

However, the availability of a motor grader in Kenya was 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 could be maintained in a given period by the same number of units of either equipment, but at a reduced cost of \$US 97 per kilometre if the tractor-towed grader units are used. However, if the availability of motor graders is reduced, the unit costs of operation will increase because of the need to reappportion depreciation and interest charges as Table 1 shows. 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 overall output per unit is likely to be the same and the cost of operation is significantly less. However, light towed grader units cannot be used to maintain badly deteriorated roads where a motor grader or heavy towed 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 25,000 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 US\$ 85 per kilometre, over US\$ 4.5 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.

8. CONCLUSIONS

Maintenance of earth and gravel roads in developing countries is normally based on the use of motor graders. Currently, there are major problems with the operation and maintenance of this relatively sophisticated equipment.

In recent years the power range of wheeled agricultural tractors has increased and these units are now widely available in developing countries.

There is potential for the development of tractor-based road maintenance as a lower cost and more effective alternative to motor graders. Foreign exchange requirements for new equipment and spares could be significantly reduced.

Tractor-based operations would offer flexibility with the same simple power source used to tow a variety of heavy duty work tools. The equipment could be supported by local labour for certain routine and periodic maintenance activities. Such an approach would encourage the greater use of local resources and development of local manufacturing capability. The technology would also be suitable for local contractors.

Tractor-based operations now offer a lower cost, sustainable and more effective alternative for the maintenance of many roads in developing countries.

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