# Towed Graders and Tractor-Based Maintenance of Low-Volume Roads

R. C. Petts and T. E. Jones

The historical development of equipment for constructing and maintaining the surface of earth and gravel roads is reviewed. The use of tractor-drawn graders and drags is emphasized. The case for tractor-based road maintenance operations for these roads in developing countries, instead of the normal motor grader and truck-based operations, is also developed. 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 labor for such activities as gravel excavation, loading and unloading, spreading, and drainage maintenance. The road maintenance could be carried out by direct labor (force account) organizations 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. Tractor-based road maintenance operations would be significantly cheaper in terms of capital and running costs. The logistic and support problems of such operations would also 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 organizations in developing countries.

In many developing countries, the motorized grader is the principal equipment item for maintaining unpaved roads. However, the availability of this equipment is low because of inadequate funding resources, mainly for spare parts and maintenance facilities, and the shortage of the trained manpower required to maintain the equipment. (The terms availability and utilization frequently used in the text refer to equipment that is available for maintenance works and is utilized in maintenance activities. Utilization is expressed as a percentage of the time that the equipment is available for work.) 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 (*2*) 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 labor for such activities as gravel excavation, loading and unloading, spreading, and drainage maintenance. The maintenance could be carried out by direct labor (force account) organizations 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 historical development of equipment for constructing and maintaining the surface of earth and gravel roads is reviewed. The use of tractor-drawn towed graders is emphasized and towed drags are briefly described. The case for tractor-based road maintenance operations for these roads in developing countries, instead of the normal motor grader and truck-based operations, is also described.

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## HISTORICAL DEVELOPMENT

Tractor or vehicle-drawn graders have been used for grading the surfaces of unpaved roads at least since 1909 (see Figure 1). Initially, they had solid metal wheels and were normally drawn by tractors (see Figure 2) although some models were self-propelled, as shown in Figure 1. Very early graders often incorporated complicated mechanical devices for carrying out activities in addition to surface grading. These included the construction of miter drains (turn outs), side drains, and side slopes, as shown in Figures 3 and 4. 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, as shown in Figures 5 and 6. This type of road construction equipment was used quite extensively in most countries until the mid-1930s when the motorized grader was developed from a hybrid tractor fitted with a full-width moldboard (Figure 7).

In developing countries, particularly in the early 1950s, the introduction of the motorized grader, often funded by developed countries or donor agencies, led to a decline in the use of tractor-towed grading equipment. However, subsequently a range of factors meant that the operation of motorized graders in developing countries became 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 20 years, a number of countries, particularly in Africa, have started to utilize tractor-towed graders for surface treatment of gravel roads (Figure 8) and, more recently, tractor-towed compactors, water

**FIGURE 1** Self-propelled grader, 1919.

**FIGURE 2** Road leveler, 1919.

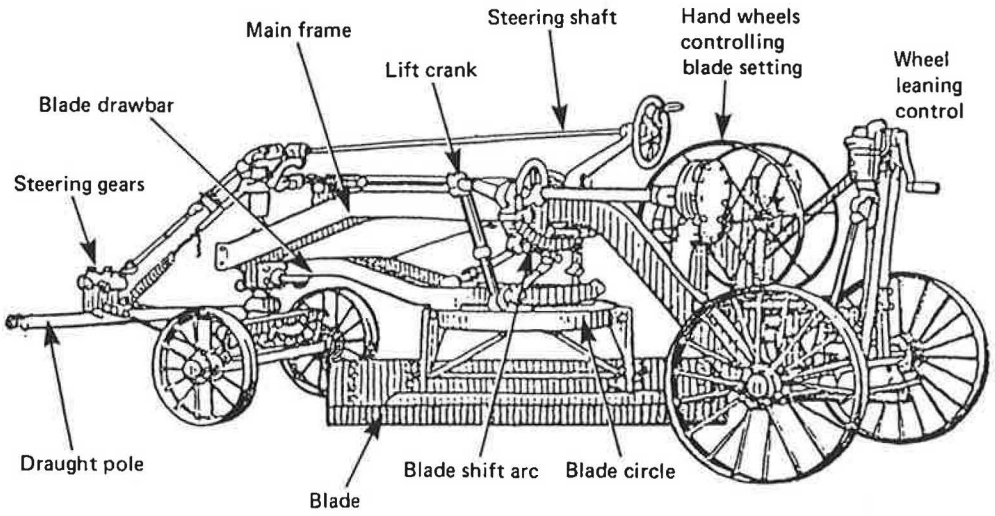
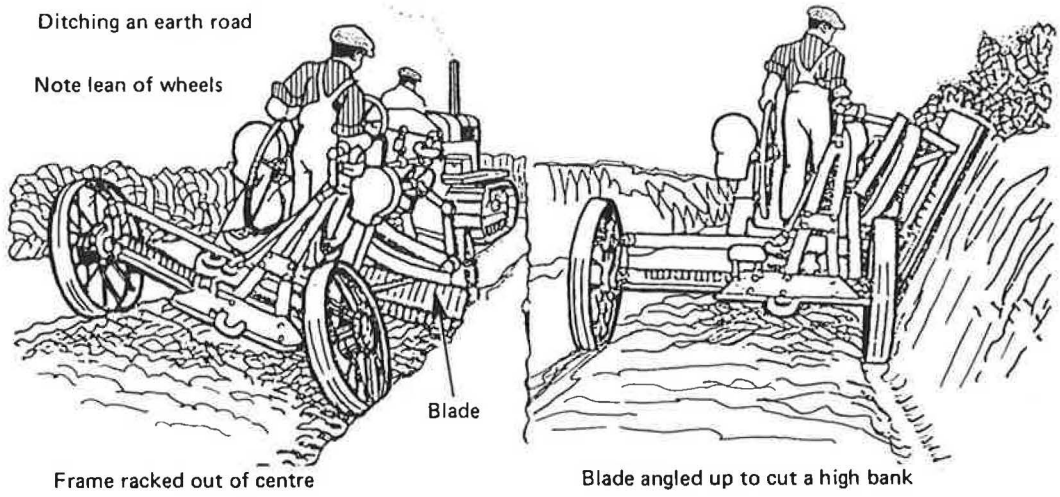



**FIGURE 3** Basic towed grader, 1920.




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

**FIGURE 4** Ditching and side slope techniques.

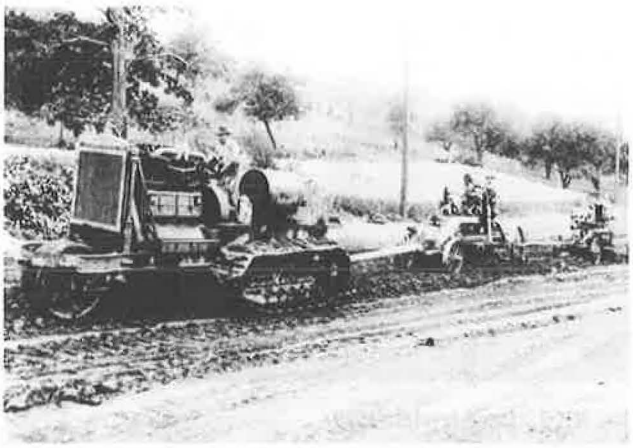


FIGURE 5 Tandem towed grader, 1920.

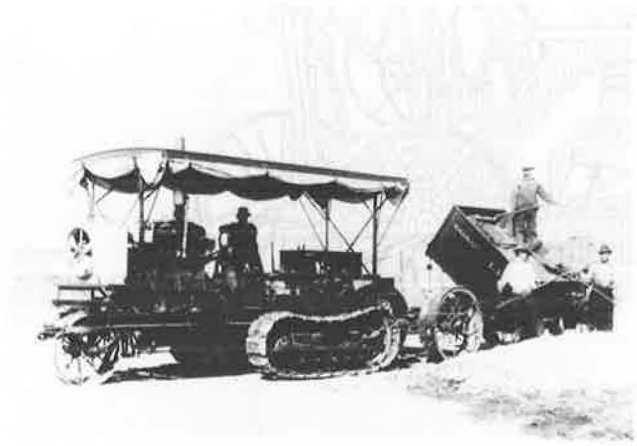


FIGURE 6 Early side-tipping trailers.

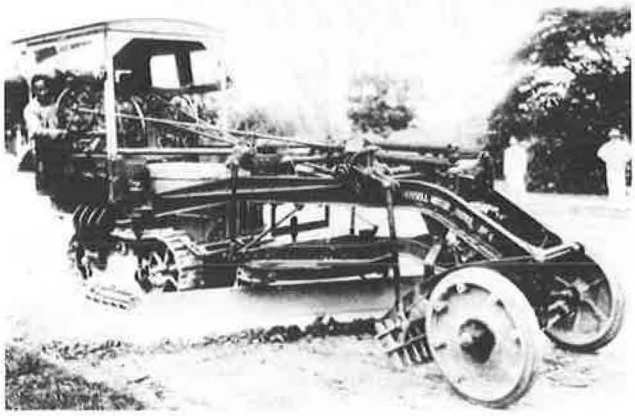


FIGURE 7 Prototype motorized grader, 1926.

FIGURE 8 Grader in use in Africa in 1960s.

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 km of unpaved road, has already started to implement such a system (Figures 9 and 10).

The development of mechanical drags for leveling unpaved roads has changed only slightly from the 1920s when the prime mover was a horse as shown in Figure 11. Early models of the drags shown in Figures 12–14 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*).

## 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.

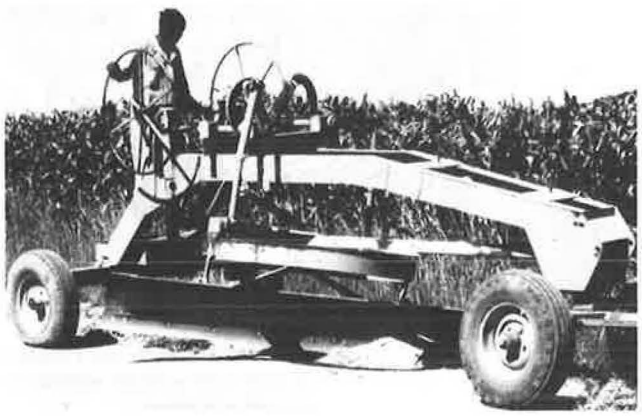


FIGURE 9 Towed grader currently utilized in Thailand.

**FIGURE 10 Tractor-towed compactor.**

The motor grader is used for reshaping the running surface, removing corrugations, and cleaning the side and miter drains (turn-outs). The machines typically work alone, operating from a road camp base. Grader operations are usually supplemented by labor 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 bowsers are used for the provision of gravel surfacing, which is required for routine patching and periodic regraveling. Haulage is normally carried out using tipping trucks.

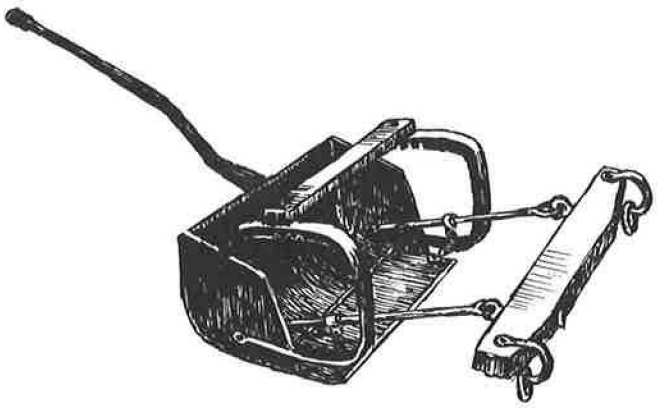


**FIGURE 11 Horse-drawn scraper.**

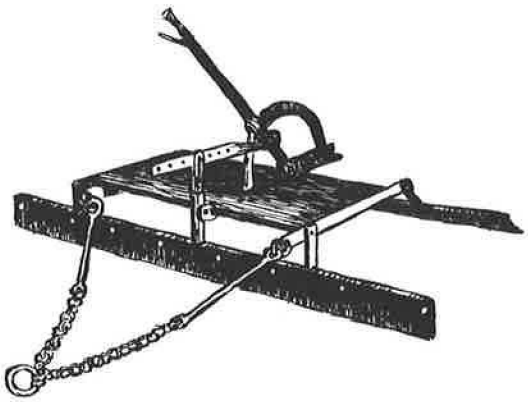


**FIGURE 12 Two-bladed adjustable road drag.**

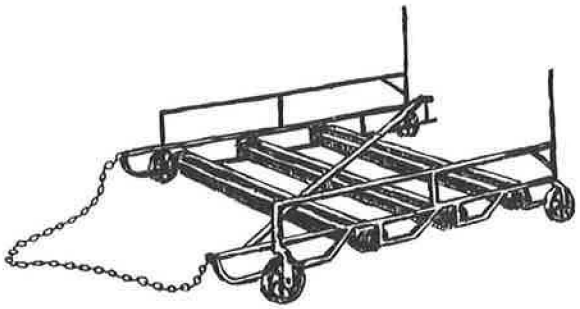


**FIGURE 13 Road hone.**

These equipment-based operations were set up before the global oil crises of the 1970s. Before 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.

The operating environment of road authorities has changed considerably over the last 20 years. Motor graders, front-end loaders, and bulldozers are now expensive and specialist items of equipment, ideally suited for use by medium or large contractors in developed countries. These organizations 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 realized in these circumstances.

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

- Equipment working individually at long distances from workshop facilities.
- Poor workshop facilities—mobile workshops rarely exist.
- Lack of 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.

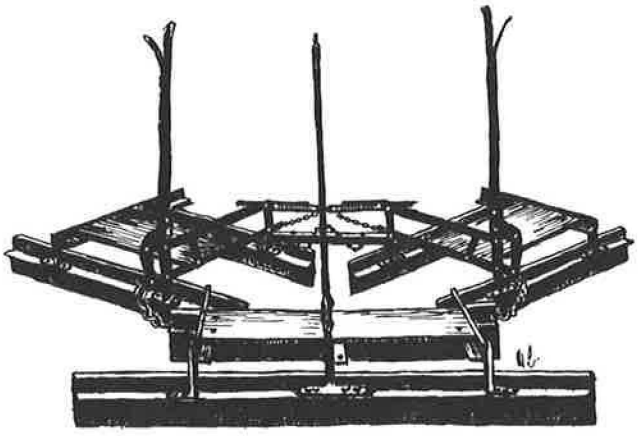


**FIGURE 14 Three-way road drag.**

- Wide variations in models and makes of equipment because of restrictive tendering (usually lowest initial cost) procedures, exacerbating spares procurement and stocking problems.
- Foreign exchange shortages exist in many developing countries so that road authorities and equipment agents have difficulties in procuring equipment and spares from abroad. These organizations 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 because of 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 these 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 to 70 percent, or more, availability (where reliable records exist) is typically of the order of 20 percent for road maintenance equipment (*3*). The cost of owning and operating equipment at these low rates is uneconomic, as Table 1 indicates.

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, because of 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.

## 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 to 80 hp are adequate for hauling towed graders of about 2 tonnes for light grading. Heavier (4-tonne) towed graders usually require tractors of 80 to 100 hp and four-wheel drive configuration. These can be used for heavy grading.

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

The capital cost of a four-wheel-drive, 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. Furthermore, the foreign exchange requirement for both capital and running costs would be reduced substantially below current levels.

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

TABLE 1 EFFECT OF UTILIZATION ON THE OPERATING COSTS OF AN ITEM OF EQUIPMENT

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

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

TABLE 2 AVAILABILITY OF AGRICULTURAL TRACTORS AND MOTOR GRADERS

| Agricultural Tractors: National Sales (All Manufacturers) | | | | | |
|---|---|---|---|---|---|
| | 40-50hp | 50-80hp | 80-110hp | >110hp | ALL |
| 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 |

| Motor Graders: Estimated Total National Fleet: All Manufacturers | |
|---|---|
| | No |
| Ministry of Public Works ..... | 350 |
| Other Organisations ..... | 150 |
| Estimated national fleet ..... | 500 |

Source: Motor Trade Association

of their high cost. Even on projects utilizing 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, indicates that their availability is over 90 percent 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. Tractor-based equipment can normally be expected to provide availability of 2 to 3 times that of the specialist road maintenance equipment.

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 regraveling. The Kenya Rural Access Roads and Minor Roads Programs have used tractor-trailer combinations to haul gravel for the construction and periodic maintenance regraveling of a road network of over 9 000 km. 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 labor accommodation could be towed in tandem with equipment between remote worksites to minimize 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 or 3 tractors based on the concept shown in Figure 15.

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

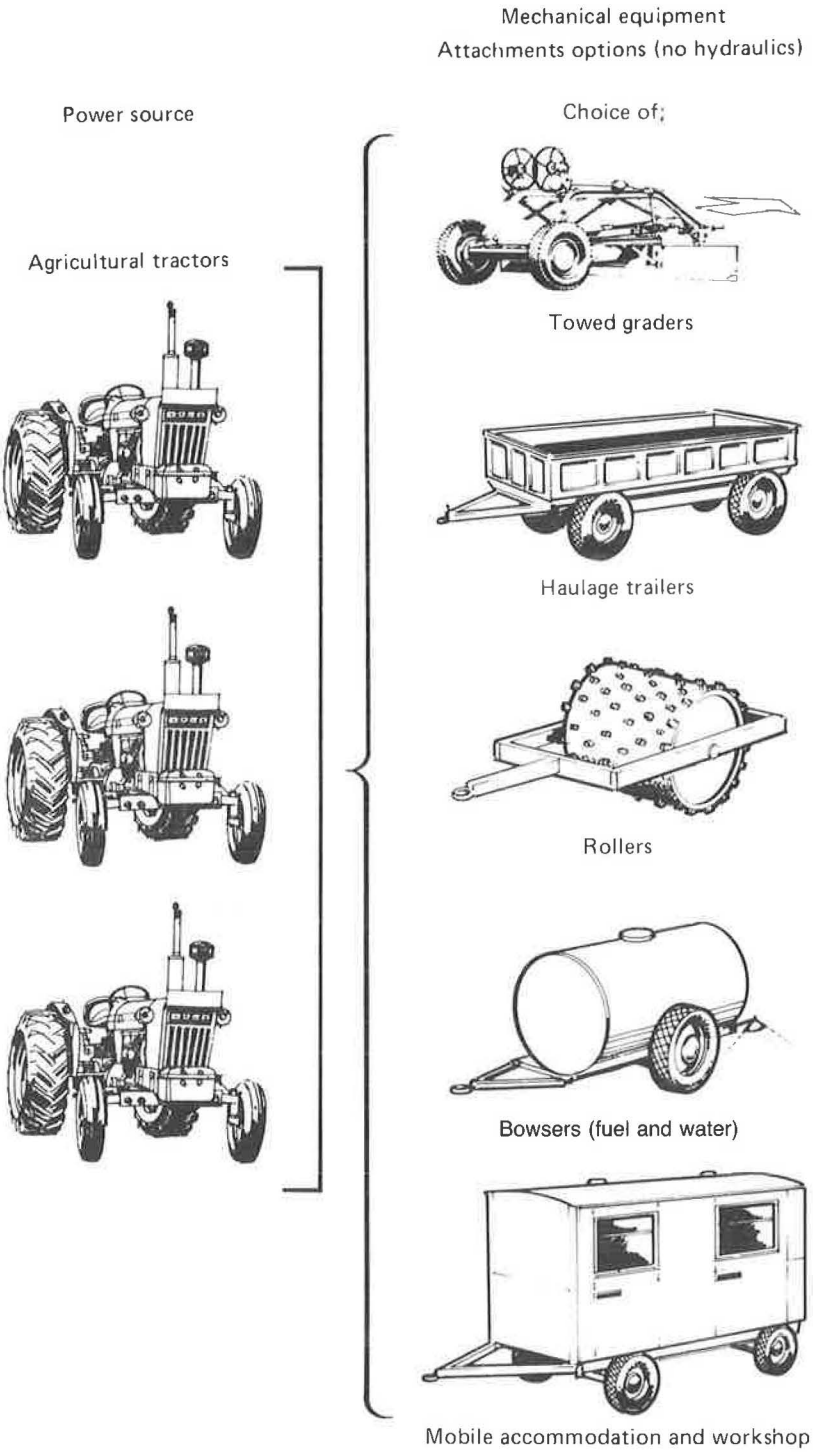
An important consideration is that all of the attachments—towed graders, gravel haulage trailers, rollers, bowsers, workshop, and mobile accommodation—could be built and therefore easily maintained in developing countries.

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.

## 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 that limits the frequency of maintenance operations. For unpaved roads in developing countries, the




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

**FIGURE 15 Flexible technology.**

motor grader is the most commonly used item of maintenance equipment. However, because of the factors already discussed they tend to have a low level of availability, particularly when compared to other types of plant used in both construction and maintenance activities (*5–7*).

### 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 percent. However, in the Kenyan regraveling program, this figure was found to be over-optimistic. In 1981, availability rates on the regraveling projects in Western and Nyanza provinces were found to average 39 percent for 13 motor graders, 8 of which were less than 2 years old. In the following year, the average had dropped to 31 percent, as indicated in Table 3.

Equipment records were not available for the other geographical areas utilized in the study, but availability of motor graders elsewhere is unlikely to have been better than these rates. All of the regraveling 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 regraveling 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 to 80 percent. In addition, some 90 tractors, nominally of 48 hp, were utilized by the Rural Access Roads Program (RARP) for gravel haulage. Since December 1981, the RARP kept detailed records of plant availability, some of which are indicated in Table 4, which presents availability and utilization rates for a 6- to 8-month period.

### Elsewhere in Africa

The TRRL found in Ghana that motor graders were only available for 10 percent of the time, compared with 30 percent for agricultural tractors utilized by the same organization (*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 percent,

TABLE 3 MOTOR GRADER AVAILABILITY IN KENYAN REGRAVELING PROJECTS (PERCENT)

| MANUFACTURER | TOTAL No | 1981 | 1982 | Average |
|---|---|---|---|---|
| A | 8 | 38 | 25 | 32 |
| B | 3 | 33 | 33 | 33 |
| C | 2 | 50 | 50 | 50 |
| Weighted average | | 39 | 31 | |

TABLE 4 TRACTOR AVAILABILITY IN THE RURAL ACCESS ROAD PROGRAM, 1981 TO 1982

| Unit | Working Days | Days Available | Days Worked | Availability (per cent) | Utilisation (per cent) |
|---|---|---|---|---|---|
| Kwale 1 | 120 | 55 | 50 | 46 | 42 |
| Kwale 2 | 138 | 78 | 38 | 60 | 28 |
| Embu 1 | 108 | 84 | 49 | 78 | 45 |
| Embu 2 | 108 | 72 | 51 | 67 | 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 | 130 | 34 | 83 | 22 |
| AVERAGE | 137 | 92 | 46 | 67 | 35 |

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

respectively (*6*). In general, the higher figures are obtained by contractors, whereas government agencies normally have lower levels of availability, some substantially lower (*7*).

In 1982, the International Labor Office (ILO) produced a list of availability and utilization rates in 10 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 percent, 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 1,824 hr for motor graders (*1*). This amount is equivalent to over 7 hr per day for 250 working days a year, which is essentially 100 percent 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 what would normally be met in practice in developing countries, with the exception of new equipment or equipment working under ideal conditions.

## CURRENT USAGE OF TOWED GRADERS

### Zimbabwe

Local manufacturers in Zimbabwe currently fabricate a 2-tonne towed grader, with a total production of over 500 to date since 1960. Of these, some 200 are currently utilized 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. These graders 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.

### Thailand

The Office of Accelerated Rural Development in Thailand, which is responsible for the construction and maintenance of 19 000 km 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 motorized graders.

### 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, e.g., volcanic and cinder materials. In Kenya, a local manufacturer is currently producing a heavier towed grader of approximately 4 tonnes. These are fully trailed units with greater load transfer on the tractor driving wheels, while the longer distance between the hitch point and rear wheels ensures a more even grade (Figures 16 and 17).

### Elsewhere

In Great Britain, towed graders are available but they are normally only utilized for light grading, e.g., on sports grounds. These are the Hallam and Simba graders. They have been

**FIGURE 16 Prototype heavy grader on trial near Nairobi.**

**FIGURE 17 Prototype heavy grader on trial on clay soils.**

used overseas, but the main drawback is that their design is more appropriate for developed country circumstances that could result in problems similar to those associated with the motor graders in developing countries, i.e., 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 motorized grader for reducing surface roughness and restoring camber. The development of the Zimbabwean or Kenyan towed grader should provide the solution.

## 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 presents 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 labor, fuel, and tires.

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 five passes in their operation manuals. In practice, the poor initial condition of the road makes more passes necessary. This situation is because of the low availability of motor graders and other factors making maintenance infrequent. Assuming five passes, it then follows that, at an average speed of 2 km/hr, it will require 5 hr of continual operation to complete 2 km. Normal daily working periods are 8 hr, but the available time for grading each day is unlikely to be greater than 5 hr, taking into consideration traveling to site, refuelling, and downtime. Therefore, the output of the motor grader is estimated at 2 km per day. This result 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 km of road are as follows: 8 hr at U.S. $45.55 = U.S. $364, i.e., U.S. $182/km.

One of the results of the TRRL study in Kenya showed that a tractor-towed light grader unit could maintain approximately 1 km of road per day. The unit requires 8 hr of operating time, so the costs of maintaining 1 km of road with these units will be as follows: 8 hr at U.S. $12.18 = U.S. $97/km.

However, the availability of a motor grader in Kenya was only 30 percent, whereas motor tractor availability is about 60 percent. 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 U.S. $97/km 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 reapportion 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 alter-

TABLE 5 HOURLY OPERATING COSTS OF MAINTENANCE EQUIPMENT, 1987

| | Motor Grader | Tractor/towed grader | Tractor/drag unit |
|---|---|---|---|
| Item | Costs/hr (US$) | Costs/hr (US$) | Costs/hr (US$) |
| Depreciation | 16.45 | 2.45 | 1.87 |
| Interest | 9.05 | 0.98 | 0.66 |
| Fixed costs | 25.49 | 3.42 | 2.54 |
| Fuel | 7.23 | 2.26 | 2.26 |
| Lubrication | 0.55 | 0.22 | 0.18 |
| Tyres | 2.11 | 0.44 | 0.35 |
| Maintenance | 5.72 | 2.10 | 1.98 |
| Cutting edges | 0.95 | 0.29 | 0.46 |
| Operators/ salaries | 3.51 | 3.51 | 1.76 |
| Running costs | 20.06 | 8.76 | 6.98 |
| Total costs | 45.55 | 12.18 | 9.52 |

native 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 for which a motor grader or heavy towed grader will still be needed.

This is not the case for the tractor-mechanical drag units that, although capable of reducing surface roughness, pothole 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 km of engineered gravel roads. If maintenance strategies utilizing tractor-towed grader units were adopted instead of motor graders, then for a grading frequency of twice a year and a cost saving of U.S. $85/km, over U.S. $4.3 million could be saved annually. It is also important to realize that, by using less complex equipment that is less reliant on imported spare parts and foreign exchange constraints, the desired maintenance is far more likely to be achieved.

## 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 at 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 labor 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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