

AGRICULTURAL TRACTORS IN ROADWORKS

Robert Petts

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TABLE OF CONTENTS

page

<i>THE MART INITIATIVE</i>	<i>1</i>
<i>ACKNOWLEDGEMENTS</i>	<i>1</i>
<i>THE AUTHOR</i>	<i>1</i>
<i>SYNOPSIS</i>	<i>2</i>
<i>ABBREVIATIONS</i>	<i>2</i>
1. INTRODUCTION	4
2. EXPERIENCE WITH TRACTORS	8
3. INTERMEDIATE EQUIPMENT	9
4. PAVED ROAD POTENTIAL	25
5. PLANT HIRE	25
6. SUB-SECTOR NEEDS	28
7. CONCLUSIONS	29

REFERENCES

ANNEX 1 - SUPPORTING LABOUR COST DATA
ANNEX 2 - SUPPORTING EQUIPMENT COST DATA
ANNEX 3 - MANUFACTURER'S DETAILS

FIGURES

- 1 *Definitions*
- 2 *Unskilled labour wage rates, construction sector 1991*
- 3 *Average daily wages (agricultural - 1991)*
- 4 *Bitumen pavement reconstruction using tractor harrow*
- 5 *Bituminous overlay using tractor towed asphalt spreader*
- 6 *Problems often associated with sophisticated imported heavy equipment for roadworks*
- 7 *Equipment utilisation - cost relationships*
- 8 *Agricultural tractor attachments for roadworks*
- 9 *3 cubic metre gravel haulage trailer for labour loading and unloading* (Tinto)
- 10 *7.5 cubic metre tipping trailer* (T. B. F. Thompson)
- 11 *Tractor towed earth moving scraper* (Reynolds)
- 12 *4,500 litre towed water bowser* (Tinto)
- 13 *2 tonne Light towed grader* (Arthur Garden)
- 14 *5 tonne Heavy towed grader* (Turbomech)
- 15 *4/5 tonne Heavy towed grader with ripper attachment* (Simba)
- 16 *Tractor with loader, harrow and light towed grader for bitumen road rehabilitation* (Colas)
- 17 *5 tonne towed deadweight roller with transport wheels* (Turbomech)
- 18 *22 tonne towed plant transporter* (T. B. F. Thompson)
- 19 *Towed engine driven road sweeper* (Phoenix)
- 20 *Tractor fitted with hydraulically driven road sweeper and 550 litre bitumen emulsion sprayer* (Phoenix)
- 21 *Suggested contractor plant holding, gravelling using heavy plant*
- 22 *Suggested contractor plant holding, tractor based contractor*
- 23 *Routine maintenance labour contractor capital costs*
- 24 *Construction of new road base layer from existing base and bituminous surfacing*
- 25 *Surfacing of reconstructed road base layer*
- 26 *Intermediate equipment sub-sector needs*

THE MART INITIATIVE

The Management of Appropriate Road Technology (MART) initiative aims to reduce the costs of constructing, rehabilitating and maintaining road infrastructure, and vehicle operations in economically emerging and developing countries (EDCs). It is based on a research project funded principally by the British Department For International Development (DFID) under its Technology Development and Research (TDR) provision. The initiative is led by the Construction Enterprise Unit of Loughborough University's Institute of Development Engineering, in association with two UK-based specialist consultants Intech Associates and I.T.Transport. The MART programme is currently implementing its initial 3 year programme.

The MART programme is concerned with supporting sustainable improvements in road construction and maintenance in developing countries. This implies the effective use of local resources, particularly human resources and readily available intermediate equipment (especially wheeled agricultural tractors and related ancillary equipment). To optimise the use of scarce financial resources, it also requires the effective mobilisation of the indigenous private sector (particularly small domestic construction enterprises), and the application of good management practices in both contracting and employing organisations.

The current phase of the MART programme will *inter alia* draw together existing expertise in labour - and intermediate equipment-based technology and the development of private construction enterprises to produce a series of guidelines on the four priority topics of:

- handtools;
- intermediate equipment;
- private sector development; and
- institution building.

The MART initiative is strongly research-based, and both DFID and the MART partners see its main impact as providing analysis and codification to support practical project initiatives. Thus much of the output will be in the form of journal papers and other formal publications suitable as reference material and providing an independent and reliable record of the advancing state of the art.

This Working Paper is intended to inform and provoke discussion and dissemination. MART welcomes dialogue with engineers, equipment designers and manufacturers regarding designs, products or experience of intermediate equipment with the objective of the promotion of a sustainable road sector technology and management approach for EDCs.

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SYNOPSIS

This working paper reviews the role of and potential for the wheeled agricultural tractor for roadworks in economically emerging and developing countries. It considers the rationale for, and range of activities suitable for, tractor applications in paved and unpaved road works.

While heavy plant may be appropriate for some large road construction and rehabilitation projects where the huge investment may be justified, for most roadworks, and particularly maintenance, tractor technology can offer a capable, cheaper and more flexible investment which is better suited to the situation of emerging and developing countries and their local contractors.

The paper demonstrates that tractor technology should be part of a natural progression from purely labour operations through to sophisticated heavy equipment roadworks, particularly with respect to capital requirements. It also shows that the owning and operating costs of tractor equipment can be considerably lower than for heavy plant to achieve the same work output.

The paper suggests that support for intermediate equipment hire organisations could help to establish tractor technology and reduce road infrastructure provision and maintenance costs.

The needs of the intermediate equipment sub-sector have been identified through the MART initiative and these are discussed.

ABBREVIATIONS

BPWA	British Public Works Association
CIDA	Canadian International Development Agency
DANIDA	Danish International Development Authority
DFID	Department For International Development (formerly ODA)
DGIS	Directorate General for International Cooperation
EDCs	economically Emerging and Developing Countries
EU	European Union
ILO	International Labour Organisation
KfW	Kreditanstalt für Wiederaufbau
LB	Labour Based
MART	Management of Appropriate Road Technology
NGO	Non-Government Organisation
NORAD	Norwegian Agency for Development Cooperation
ROPS	Roll Over Protection Structure
SDC	Swiss Development Cooperation and Humanitarian Aid
SIDA	Swedish International Development Authority
t	tonne
TDR	Technology Development and Research
TRL	Transport Research Laboratory
USAID	United States Agency for International Development
4WD	Four wheel drive

Figure 1 - DEFINITIONS

There are various definitions and interpretations of terminology used in the appropriate technology roadworks sector. The author suggests the following definitions:-

LOCAL RESOURCES

These can include human resources, local government, private, NGO and community institutions, local entrepreneurs such as contractors, consultants, industrialists and artisans, local skills, locally made or intermediate equipment, local materials such as timber, bricks, and marginal materials, locally raised finance or provision of materials or services in kind.

LABOUR BASED ROADWORKS

Operations carried out principally by manual methods. They may be supported by intermediate or sophisticated equipment for activities not ideally suited to labour methods, e.g. medium-long distance haulage, heavy compaction. Labourers usually walk or cycle to work each day from their homes.

INTERMEDIATE EQUIPMENT

Simple or intermediate equipment designed for low initial and operating costs, durability and ease of maintenance and repair in the conditions typical of a limited-resource environment, rather than for high theoretical efficiency. It is preferable if the equipment can also be manufactured or fabricated locally.

HEAVY PLANT

Sophisticated civil engineering equipment designed for, and manufactured in, high-wage, low-investment-charge economies. Expected to operate with close support and high annual utilisation. Usually designed for a single function with high efficiency operation.

Intech Associates

1. INTRODUCTION

Economically emerging and developing countries (EDCs) vary enormously in their economic, resource, industrial, service sector and social circumstances. This suggests that the technologies and methods used for road construction, rehabilitation and maintenance should also vary and be appropriate for their individual circumstances. Unfortunately it is not always immediately obvious that the “state-of-the-art” technologies used and taught in developed country organisations and institutions are often not appropriate, economic nor sustainable in *most* situations in many other countries. What is required is an *Appropriate Technology and Management* approach.

Economically emerging and developing countries (EDCs) are usually characterised by a resource base that is very different from that found in economically developed countries. For example in developed countries labour wage rates are typically in the range of US\$40 to 150 per day equivalent (Figures 2 and 3). In comparison, EDCs may have abundant low cost and under-utilised labour (wages often less than US\$5/day equivalent), particularly in the rural areas (Figure 3). Furthermore they have local traditions and procedures, and a fledgling or intermediate-technology industrial and service sector base¹⁻³ which are substantially different from the industrialised countries. It makes economic and management sense to seek an optimal use of these lower cost, locally available resources, including local skills and traditions before resorting to importing expensive (and often extremely problematic) heavy equipment and expertise on a large scale.

Heavy construction plant will still continue to be justifiable on many large, paved main road, reconstruction and rehabilitation projects where the factors of high road traffic, high technical specifications, high guaranteed plant utilisation, economies of scale, intensive management, rapid implementation and relatively simple logistics can support a large-contractor, capital-intensive approach. However for most other roadworks the use of intermediate equipment and labour is often cheaper and more appropriate. There are also strong political and social arguments for adopting a more local-resource orientated approach.

Many problems encountered in the road sector in EDCs can be attributed to the application of inappropriate technology, as well as problems of inadequate policy guidance, insufficient funding, inadequate institutional arrangements, poor manpower development and motivation, and inadequate decision making arrangements⁴⁻⁹.

This paper reviews the experience and potential role of tractor technology in the development of an appropriate and sustainable road sector in EDCs. By adopting the most appropriate *technology* in each situation (whether labour, intermediate or heavy equipment) it should be easier to tackle the other (equally important) issues of finance, institutional arrangements and management.

Figure 2

Figure 3

(Figure 3 continued)

2. EXPERIENCE WITH TRACTORS

The use of wheeled agricultural tractors is well established in the private and public sectors in many EDCs for road, agricultural and water sector works.

Even on many of the labour based (LB) road programmes, tractors and fixed dump body trailers are used for hauling natural gravel for the running surface of roads; with excavation, loading and unloading achieved by manual labour. Gravel road construction/ rehabilitation is typically achieved for a cost of US\$10,000 to 20,000 per km using tractor and labour technology (with labour wage rates of between US\$1 and 3.5 per day)¹⁰.

On conventional capital intensive road projects, wheeled agricultural tractors are normally used for tasks such as towing compaction rollers and water bowsers, and sweeping.

In the UK some contractors still use tractor technology for rehabilitating thin-surfacing paved minor roads using bitumen emulsion technology, and for laying thin bituminous overlays (Figures 4 & 5). The operations include ripping, pulverising, mixing and spreading by tractor equipment. The bitumen roadworks viability of tractor technology in the relatively high wage environment of the UK presents the prospects of tractor technology being attractive in a far greater range of economic circumstances than pure labour technology when the wage rates in Figures 2 and 3 are considered.

Many of the LB road programmes in EDCs have concentrated on road construction or rehabilitation, rather than maintenance. The method of implementation has focussed on works management using a civil service organisation, with the notable exception of the Ghana, Lesotho, Tanzania and Indonesia projects^{11-14, 22}. The programmes have usually concentrated on gravel roads (unpaved roads often constitute between 80% to more than 90% of national road networks in EDCs¹⁵).

Despite this encouraging experience with agricultural tractors, most roadworks in EDCs are still carried out by civil service organisations or large contractors using traditional heavy equipment technology.

There is now widespread pressure, particularly from the international agencies and some governments, for a move away from implementation using the problematic civil service machinery, towards works carried out by the private sector. In addition more attention is being paid to road maintenance. There is also strong argument for better use of local resources^{6,7,9,15,16}. It is argued that with the expected commercial pressures more attention will be paid to cost awareness and the adoption of the most appropriate technology.

Unfortunately the road contracting sector is poorly developed in many of these

countries after decades of force account^a road maintenance operations. Typically major road schemes are carried out by international contractors, a few large indigenous contractors, or a partnership of both. However, the majority of roadworks (smaller schemes and most maintenance) is suitable for lower cost appropriate technology implementation by small domestic contractors using simple equipment and local labour. There should also be scope for sub-contracting to the larger projects. Unfortunately the appropriate standards, documentation, procedures, awareness and training, and supporting institutional and management framework to use an appropriate technology approach are usually deficient.

3. INTERMEDIATE EQUIPMENT

Intermediate equipment often is, or can be, manufactured locally to meet some of the needs of the roadworks sector. It can be tractor-based, self propelled, animal drawn or hand operated. Capital costs of local manufacture can be significantly lower than imported sophisticated equipment. Other potential benefits include easier maintenance, simpler spares requirements leading to less downtime (i.e. higher availability), lower operating costs and the added advantage of the local manufacturing capability (which creates local employment). This should encourage greater sustainability compared to sophisticated imported equipment (Figure 6)^{2,17,18}.

Experience has shown that the use of heavy plant for road maintenance works in EDCs leads to extremely low utilisation rates for the equipment due to a range of factors in Figure 6. Annual utilisation can often be in the region of 200-500 hours per year^{19,27}. At this level of utilisation the overall costs of ownership in EDCs is extremely high (Figure 7) and uneconomic.

In contrast, tractor equipment is likely to achieve far higher availability in any particular mechanical support environment²⁷. Slightly reduced hourly output by lower-powered tractor equipment can be more than compensated with higher availability and overall output, and far greater utilisation due to flexibility of applications.

With the grading application shown in Figure 7 it should also be recognised that typical (and adequate) motorgrader specifications in the period 1945-55 were only 75-100 hp (56-75 kW) and 10 tonne operating weight (e.g. Caterpillar 12)²⁹. This is comparable to the larger tractor-based combinations now available (5 tonne 100 hp tractor and 5 tonne towed grader) which can achieve both light and heavy grading.

^a *Force Account: Road authority carrying out works using its own permanent manpower and equipment fleet.*

FIGURE 4 - Bitumen pavement reconstruction using tractor harrow

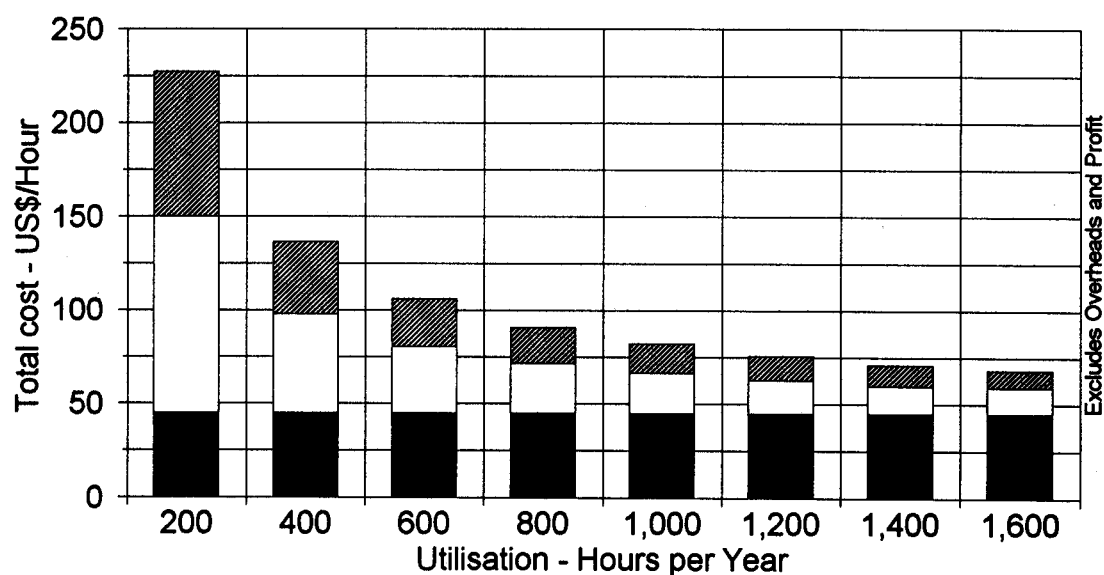
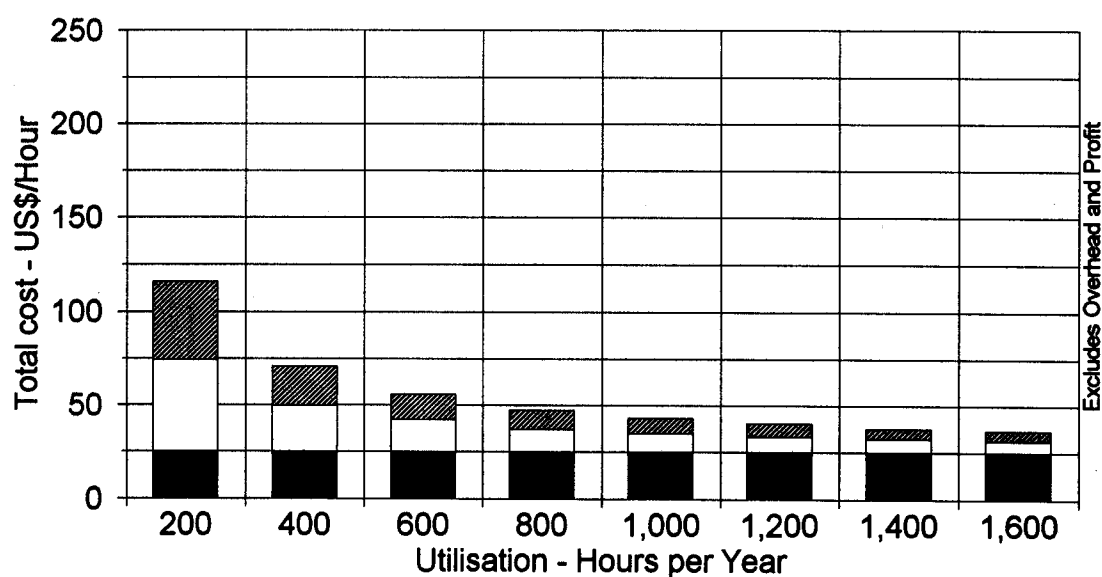
FIGURE 5 - Bituminous overlay using tractor towed asphalt spreader

Figure 6 - PROBLEMS OFTEN ASSOCIATED WITH SOPHISTICATED IMPORTED HEAVY EQUIPMENT FOR ROADWORKS

- Dedicated function (can only be used for one operation)
- Inter-dependence (e.g. dozer, loader, trucks, motorgrader, bowser, roller all required for gravelling - what happens when ONE link in the chain breaks down?)
- All equipment and spares imported - consuming scarce foreign exchange
- Long spares supply lines and delivery times
- Limited local market for equipment sales of each model
- Few dealers able to provide the necessary close support
- High capital costs
- High costs of stocking and provision of spares
- High pressure hydraulic systems
- Sophisticated mechanisms
- Specialist repair and maintenance skills, tools and facilities required (often only available in the capital city)
- Frequent model “improvements” causing spares stocking and procurement problems and “planned” obsolescence
- Disposable components; difficult to repair or refurbish
- Lack of continuity of workload for plant items of dedicated function

RESULT - low availability & high overall costs!

Intech Associates

Figure 7 - **EQUIPMENT UTILISATION - COST RELATIONSHIPS****COST VARIATION WITH UTILISATION****120 hp MOTORGRADER****COST VARIATION WITH UTILISATION****100 hp 4WD TRACTOR + 5t TOWED GRADER**

Based on 12 year economic life for the motorgrader and 10 years for the tractor equipment. Calculated on an interest rate of 20%. For detailed assumptions and calculations see Annex 2. Motorgrader hourly output on light and heavy grading expected to be 20% higher than towed grader.

Wheeled agricultural tractors are the simplest, most robust and versatile mobile power source; furthermore the proven uses in the road sector are extensive (Figure 8). Applications cover bitumen, gravel and earth roads. Even where the tractors are not manufactured or assembled locally, the attachments usually can be. Tractor technology suffers much less from the problems summarised in Figure 6. Figures 9 to 20 illustrate some of the tractor equipment applications in roadworks.

Figure 8 - AGRICULTURAL TRACTOR ATTACHMENTS FOR ROADWORKS

The following attachments can be fitted to wheeled agricultural tractors in the power range 50 - 100 hp (37-75 kW) for road construction, rehabilitation and maintenance. Often only minor tractor modifications are required, such as the fitting of a heavy duty hitch and Roll Over Protection Structure (ROPS). Four wheel drive, industrial tyres and improved dust filtration are recommended for some applications. The attachment designs and fabrication need to be robust for roadworks use:

Earthworks/Unpaved Roads

- Towed Gravel Haulage Trailer (*Figs. 9 & 10*)
- Towed Earth Scraper (dam scoop) (*Fig. 11*)
- Towed Drag
- Towed Water Bowser/Sprayer (*Fig. 12*)

Paved Roads

- Planer/Milling Attachment
- Towed/Attached Bitumen/Emulsion Heater/Distributor (*Fig. 20*)
- Towed Bitumen Slurry Seal Mixer
- Towed Premix Manufacture Equipment
- Towed Bitumen Mix Spreader (*Fig. 5*)

General Roadworks Applications

- Heavy Duty Automatic Pick-up Hitch
- Light Towed Grader (Up to 3 Tonnes) (*Figs. 13 & 16*)
- Heavy Towed Grader (Over 3 Tonnes) (*Figs. 14 & 15*)
- Lime/Cement/Bitumen/Mechanical Stabilisation Harrow/Mixer Attachments (*Figs. 4 & 16*)
- Towed Rubber Tyred Roller
- Towed Steel Wheel Roller (deadweight/vibrating) (*Fig. 17*)
- Front End Loader Attachment (*Figs. 4 & 16*)
- Ripper Attachment (*Fig. 15*)
- Towed Accommodation/Workshop Caravans
- Towed Fuel Bowser
- Towed/Attached Concrete Mixer
- Towed Compressor and Pneumatic Tools
- Towed Mobile Stone Crushers and Screens
- Rotary Grass Cutter
- Powered Sweeper/Broom (*Figs. 19 & 20*)
- Low Loader Trailer (*Fig. 18*)

Sources: manufacturers/suppliers

Service and repair facilities for agricultural tractors are far more common in rural areas than for heavy civil engineering plant. This contributes to better reliability and availability of the equipment.

Recent experience in Kenya¹⁹ has shown that a team of three No. 100hp 4wd tractors working in association with two 5 tonne heavy towed graders (Figure 14), a towed compaction roller and local unskilled labour can rehabilitate the camber and drainage system on earth and gravel roads for direct costs of less than US\$2,000 per km. The rate of work output was more than 2 km of rehabilitated road per week.

Subsequent routine maintenance can be established for between US\$250 - 750 per km per year, depending on towed grading frequency, also using labour and tractor technology. These costs are substantially below those of using a heavy plant approach.

This basic provision of camber and drainage system **AND** regular low-cost routine maintenance can provide an adequate standard of low traffic road in low-moderate rainfall climates (<2,000 mm/year). Spot gravelling, or even more extensive gravelling where traffic and resources permit can also be provided at costs lower than using heavy plant.

Figure 10 7.5 cubic metre tipping trailer (T. B. F. Thompson)

Figure 11 Tractor towed earth moving scraper

(Reynolds)

Figure 12 4,500 litre towed water bowser

(Tinto)

Figure 13 2 tonne Light towed grader
Figure 14 5 tonne Heavy towed grader

(Arthur Garden)
(Turbomech)

Figure 15 4/5 tonne Heavy towed grader with ripper attachment (Simba)

Figure 16 Tractor with loader, harrow and light towed grader for bitumen road rehabilitation (Colas)

Figure 17 5 tonne towed deadweight roller with transport wheels

(Turbomech)

Figure 18 22 tonne towed plant transporter

(T. B. F. Thompson)

- Figure 19 Towed engine driven road sweeper (Phoenix)*
Figure 20 Tractor fitted with hydraulically driven road sweeper and 550 litre bitumen emulsion sprayer (Phoenix)

Tractor technology offers local entrepreneurs a lower risk and more flexible investment than traditional heavy roadworks plant. The latter will require investments in specialised equipment with a new procurement cost of about US\$1 million or more (figure 21), even to achieve just a full regravelling capability (with high associated running costs).

In practice, contractors will often purchase second-hand plant from larger contractors or overseas sources. Nevertheless the risks from undocumented previous use and abuse are obvious, with the potential for poor availability of spares and expensive repairs for the new owner.

However, from as little as US\$30,000, a contractor or subcontractor can buy (new) into tractor technology with the versatility to carry out a range of operations and serve clients in the road, agriculture, water and municipal sectors (Figure 22). An extensive roadworks, water and agricultural sector capability using tractor technology can be achieved with an investment of less than US\$250,000 (new). This is equivalent to the cost of just one new motorgrader. The tractor based equipment substantially reduces the risks and increases business opportunities compared to a 'one client' relationship using single-function items of plant. Nevertheless, the development of an effective multi-sector tractor-based contracting sector will require improved understanding, liaison and cooperation between road authorities, agricultural organisations, land users, equipment owners, suppliers and manufacturers.

Tractor technology also creates a natural development path for successful pure-labour contractors, who can be established for capital sums of about US\$12,000 (Figure 23), when they come up against the management constraints of large unskilled labour forces.

FIGURE 21**SUGGESTED CONTRACTOR PLANT HOLDING
GRAVELLING USING HEAVY PLANT**

ITEM	UNIT CAPITAL COST NEW# (US\$)	NO. IN FLEET	ITEM CAPITAL COST (US\$)
Tracked Loading Shovel (Cat 953)#	215,000	1	215,000
Tipper 4x2, 7t ##	55,000	5	275,000
Motorgrader (Cat 140)	250,000	1	250,000
Self propelled Roller	85,000	1	85,000
Fuel Bowser Truck	60,000	1	60,000
Water Bowser Truck	55,000	1	55,000
Service Truck	60,000	1	60,000
Supervision Pick-up	20,000	1	20,000
TOTAL (US\$)			1,020,000

NOTES

- # *Compromise, instead of dozer plus wheeled loader*
10t or 15t tippers would probably be more economic
* *Excludes low loader for plant transportation between sites (typical hire at US\$4/km)*
** *No allowance for standby items*
*** *Prices based on typical delivered cost including taxes and duties*
**** *1997 prices*

Source: Intech, Kenya market prices.

FIGURE 22**SUGGESTED CONTRACTOR PLANT HOLDING
TRACTOR BASED CONTRACTOR****I - BASIC TRACTOR EQUIPMENT FOR ROUTINE MAINTENANCE**

55hp (41kW) 4x2 agricultural tractor	US\$22,000
5t fixed body heavy duty trailer	US\$6,000

Sub Total	US\$28,000

Optional 2t towed grader	US\$8,000
Optional towed water bowser	US\$8,000
Optional pedestrian vibrating roller	US\$12,000

TOTAL	US\$56,000
	=====

NOTE *It is recommended that the optional equipment is hired if possible, particularly where annual utilisation will be low.*

**II - BASIC TRACTOR EQUIPMENT FOR EARTH/GRAVEL ROAD
RECONSTRUCTION**

2 No 100hp(75kW) 4X4 agricultural tractors	US\$100,000
2 No 5t heavy towed graders	US\$80,000
1 No towed deadweight roller with transport wheel	US\$25,000
1 No towed fuel bowser	US\$8,000
1 No towed water bowser	US\$8,000
1 No pickup truck	US\$20,000

TOTAL	US\$241,000
	=====

NOTE *Tipper or flat bed trucks can normally be hired for the gravel haulage, with local unskilled labour for quarry development, excavation, loading, (unloading if necessary) and spreading of gravel. This considerably reduces capital investment requirements for the contractor.*

Source: Intech Associates, 1997 Kenya prices

FIGURE 23 - ROUTINE MAINTENANCE LABOUR CONTRACTOR CAPITAL COSTS

ITEM	COST (US\$ EQUIVALENT)	
	For 100 km of road	For 150 km of road
1. SECONDHAND PICK-UP Assumed life of 4 years	8,000	8,000
2. BICYCLES @ 1 per 15 km Each cost US\$ 100 Assumed life of 3 years	700	1,000
OFFICE FURNITURE Assumed life of 10 years	450	450
S/H TYPEWRITER Assumed life of 4 years	200	200
HANDTOOLS STOCK - store & issued (numbers in brackets for 100/150km)		
Hoes (55/80) @US\$ 3.5	193	280
Shovels (55/80) @US\$ 7.0	385	560
Bush Knives (55/80) @US\$ 3.5	193	280
Slashers (55/80) @US\$ 3.5	193	280
Rakes (55/80) @US\$ 4.0	220	320
Sharpening Files (55/80) @US\$ 3.0	165	240
Wheelbarrows (4/6) @US\$ 50.0	200	300
Hand Rammers (7/11) @US\$ 10	70	110
Culvert Tools (7/11) @US\$ 10	70	110
Mason's Hammers (7/11) @US\$ 5	35	55
Mattocks (7/11) @US\$ 6	42	66
Axes (7/11) @US\$ 5	35	55
Crow Bars (2/3) @US\$ 6	12	18
Sledge Hammers (2/3) @US\$ 10	20	30
Pickaxes (2/3) @US\$ 10	20	30
Claw hammers (2/3) @US\$ 10	20	30
Tape Measures (7/11) @US\$10	70	110
Ditch Templates (7/11) @US\$ 10	70	110
Camber Boards (7/11) @US\$ 10	70	110
Spirit Levels (7/11) @US\$ 10	70	110
Boning Rods (1 set) @US\$ 15	15	15
Line & Level (1 set) @US\$ 8	8	8
TOTALS (US\$)	11,526	12,877

Source: Intech Associates, 1995 Uganda prices

When considering adoption of an intermediate equipment approach, a frequently

voiced concern is what to do with the existing fleets of problematic heavy plant which are still viewed as a resource, despite their high operating costs and downtime. The rational approach would be to consolidate the remaining serviceable items on closely supported road construction/rehabilitation sites where the necessary support and the logistical problems are minimised. Replacement of the heavy plant should only be considered when the numbers reduce to a level that matches the market and economic requirements.

4. PAVED ROAD POTENTIAL

Wheeled agricultural tractors have been used independently for all of the key activities required for reconstruction of a deteriorated paved road with a thin bituminous surfacing^{2,17,18,20,21}. There is potential for contractors to carry out these works using tractor based equipment for ripping up the existing pavement, pulverising the existing materials, applying and mixing in a stabiliser such as bitumen emulsion binder, shaping and rolling, then sealing with a conventional surface dressing. The approach would optimise the use of the existing pavement materials, have the energy and environmental attractions of a cold, low waste process and should have capital requirements and overall costs significantly below those of traditional heavy plant, hot-mix reconstruction processes.

Figures 24 and 25 demonstrate how tractor technology fits into the natural progression from pure labour technology through to sophisticated equipment while still providing the flexibility provided by labour to carry out a range of operations.

Tractor towed equipment can also be used to provide thin (up to 50mm) bituminous overlays using the equipment shown in Figure 5.

5. PLANT HIRE

Bank interest rates in developing countries are usually high (15 - 48% in the countries surveyed by MART Working Paper No 2²⁸). The high cost of (and problems of securing) finance in emerging and developing countries and the utilisation-cost relationships shown in Figure 7 demand that any equipment (whether heavy or intermediate) must be highly utilised to have a chance of paying back its investment and, for a contractor, to make a profit. The market for contract roadworks in most developing and emerging countries is particularly variable and precarious. Contractors must minimise the eventualities of having serviceable-but-idle plant. There is therefore potential for the provision of intermediate equipment hire services. This could be provided by dedicated plant hire firms or by contractors hiring out their equipment when they have insufficient work themselves. This flexibility should increase the utilisation of individual items of plant and therefore lower the overall costs. Initiatives will probably be required to convince road authorities, contractors and international agencies of the potential benefits of such an approach using intermediate equipment. Pilot schemes should allow the potential, technicalities, costs and benefits of such an approach to be established.

FIGURE 24 - CONSTRUCTION OF NEW ROAD BASE LAYER FROM EXISTING BASE AND BITUMINOUS SURFACING*
PAVED ROAD RECONSTRUCTION - TECHNOLOGY OPTIONS FOR EACH OPERATION - TRACTOR OPTIONS SHOWN EMBOLDENED

COLD PROCESS EMULSION TECHNOLOGY: Options shown generally in increasing complexity of technology down each column

1. BREAK UP EXISTING PAVEMENT	2. BREAK DOWN PAVEMENT MATERIAL TO ACCEPTABLE SIZE	3. APPLY BITUMEN EMULSION	4. MIX EMULSION AND RECYCLED PAVEMENT MATERIALS	5. SHAPE MIXED MATERIAL TO FORM NEW ROAD BASE LAYER	6. ROLL ROAD BASE LAYER	7. TEST ROAD BASE LAYER
<p>Labour with picks, mattocks, sledgehammers, crowbars, shovels</p> <p>Labour with compressor and breaker tools</p> <p>Wheeled tractor with ripper attachment</p> <p>Wheeled tractor with pulveriser/milling attachment</p> <p>Tracked tractor with ripper attachment</p> <p>Self propelled milling equipment</p>	<p>Labour with sledgehammers, stone hammers and steel mesh</p> <p>Wheeled tractor with adapted towed roller</p> <p>Wheeled tractor with pulveriser/milling attachment</p> <p>Self propelled pulveriser/milling equipment</p>	<p>Labour using fixed volume containers per unit area</p> <p>Labour with one barrel hand lance</p> <p>Wheeled tractor with towed/attached bitumen distributor</p> <p>Truck mounted distributor</p>	<p>Wheeled tractor with heavy duty disc harrow</p> <p>Wheeled tractor with reciprocating harrow</p> <p>Wheeled tractor with heavy towed grader</p> <p>Motor grader</p>	<p>Labour with rakes and shovels</p> <p>Wheeled tractor with heavy towed grader</p> <p>Motor grader</p>	<p>Labour with twin drum pedestrian vibrating roller</p> <p>Wheeled tractor with towed deadweight roller**</p> <p>Wheeled tractor with towed vibrating roller</p> <p>Self propelled deadweight roller**</p> <p>Self propelled vibrating roller</p>	<p>Level and thickness control</p> <p>Grading - sieve analysis</p> <p>Voids</p> <p>Bitumen content</p> <p>Benkelman Beam</p> <p>Falling weight Deflectometer</p>

Source: Intech Associates

* The process can also be applied to the upgrading of an existing gravel surface of suitable material characteristics.

** Depending on deadweight per unit width of roll and layer thickness

*** Assumes that subgrade and/or sub base are of acceptable characteristics and any necessary repairs to the drainage system are carried out.

FIGURE 25 - ***SURFACING OF RECONSTRUCTED ROAD BASE LAYER***

PAVED ROAD RECONSTRUCTION - TECHNOLOGY OPTIONS FOR EACH OPERATION - TRACTOR OPTIONS SHOWN EMBOLDENED

COLD PROCESS EMULSION TECHNOLOGY

Options shown generally in increasing complexity of technology down each column

FIRST COAT		SECOND COAT		OPTIONAL SLURRY SEAL		
1. APPLY FIRST SEAL COAT	2. APPLY STONE CHIPPINGS (20/14 mm)	3. APPLY SECOND SEAL COAT	4. APPLY STONE CHIPPINGS (10/6 mm)	5. MIX SLURRY	6.SPREAD SLURRY	7. TESTING
Labour using fixed volume containers per unit area Labour with one barrel hand lance Wheeled tractor with towed/attached bitumen distributor Truck mounted distributor	Labour by hand from wheeled tractor towed trailer Labour by hand from truck Tipper truck with tailgate chipper Self propelled chipping spreader	Labour using fixed volume containers per unit area Labour with one barrel hand lance Wheeled tractor with towed/attached bitumen distributor Truck mounted distributor	Labour by hand from wheeled tractor towed trailer Labour by hand from truck Tipper truck with tailgate chipper Self propelled chipping spreader	Labour with concrete mixer Wheeled tractor and towed concrete mixer Truck mounted concrete mixer Truck or tractor towed slurry mixer Truck mounted slurry mixer	Labour with measuring boxes and squeegees Tractor or truck towed slurry box Truck mounted slurry distributor	Stone material Chipping sizes and cleanliness Bitumen rate of spread Visual inspections
Light compaction by tractor towed or self propelled rubber tyred or deadweight drum roller, ensuring that stone chippings are not crushed				Optional 3rd coat to form a 'Cape Seal'		

Source: Intech Associates

* The process can also be applied to the maintenance resealing of an existing bituminous surfacing (usually only one of the coats will be applied in this case).

** Time periods between roadbase construction and each seal, and trafficking, to depend on curing times.

6. SUB-SECTOR NEEDS

The MART initiative has been investigating the needs of the intermediate equipment sub-sector through questionnaires to users in developing countries. Furthermore a workshop in Accra in 1996 ²⁶ involved road and equipment engineers, contractors, consultants, academics and equipment manufacturing representatives to identify and enumerate the needs of the sector in more detail. These requirements are summarised in Figure 26.

FIGURE 26 - INTERMEDIATE EQUIPMENT SUB-SECTOR NEEDS

- **Awareness** creation concerning availability and performance
- **Cost-awareness** regarding all equipment (& particularly intermediate equipment)
- **Designs and specifications** for procurement
- **Procurement** guidelines
- **Management and support** guidelines
- **Training** in management, support and operation
- Availability of **finance**
- Availability for **hire**
- **Dissemination** of information

Source: MART

The MART initiative is preparing guidelines from available sources in consideration of the above sub-sector needs.

The MART investigations have shown that there is still a need for widespread enlightenment regarding the capability of intermediate equipment, including tractor applications. Furthermore there is prevailing lack of knowledge regarding the real costs of owning and operating any type of equipment, be it sophisticated or simple.

There is a need to highlight the real costs of financing and ownership which are neglected in many equipment management systems, and which can dwarf operating costs in a high-cost-finance environment; thus possibly adversely affecting management decisions on choice of technology or equipment.

7. CONCLUSIONS

Heavy construction plant will still continue to be justifiable on many large, paved main road, reconstruction and rehabilitation projects where the factors of high road traffic, high technical specifications, high guaranteed plant utilisation, economies of scale, intensive management, rapid implementation and logistics can support a large-contractor, capital-intensive approach.

However, the use of intermediate technology equipment and labour has particular advantages for road authorities and smaller contracting enterprises on more modest road construction/rehabilitation works and on the secondary and minor roads which comprise the majority of the rural road networks. This approach is also appropriate for most road maintenance operations on paved, gravel and earth roads.

The wheeled agricultural tractor is a proven technology for a wide range of roadworks in economically emerging and developing countries (and even for some applications in economically developed countries). However the application and benefits of tractor technology are not widely recognised or utilised. The principal attractions are lower operating and overall works costs due to reduced capital requirements and risks, higher potential utilisation through a range of applications, potential clients and workload in various sectors. Tractor technology represents the natural progression (in terms of affordability, management and business development) for authorities and contracting enterprises from pure labour operations through to the capability to utilise sophisticated heavy equipment. It should however be questioned whether most local enterprises need to complete the progression beyond tractor technology because of the costs, risks and market characteristics discussed in this paper.

There are potentially considerable benefits to be gained from encouraging the establishment of local plant hire companies providing intermediate equipment based on tractor technology. This would further assist small local contractors in reducing their capital or borrowing requirements so that they would use and pay for specific tractor equipment items only when they have secured work contracts. Contractors could also be encouraged to hire out serviceable-but-idle equipment to other contractors.

Better understanding of the capabilities, flexibility, actual costs and advantages of this technology is necessary, particularly by the engineers, contractors, suppliers of tractor based equipment, academics and trainers. Where necessary, contract procedures and documentation need to be adapted to accommodate the use of local contractors and appropriate technology. As well as adopting the most appropriate *technology* in each situation (whether labour, intermediate or heavy equipment) attention must also be paid to tackling the other (equally important) issues of finance, institutional arrangements and management in the roadworks sector.

The MART initiative is assisting in these endeavours by codifying and disseminating the experiences and potential of intermediate equipment technology and local

contracting.

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ANNEX 1 - SUPPORTING LABOUR COST DATA

The data in this Annex has been used to prepare the Figures 2 & 3 in the main text.

ANNEX 2 - SUPPORTING EQUIPMENT COST DATA

The data in this Annex has been used to prepare Figure 7 in the main text. The costing method used for this example figure has been developed for the MART equipment guidelines which are currently under preparation.

The costing method is designed to include all cost components relating to the ownership, operation and overheads components. The approach may be used for any type of intermediate or sophisticated equipment.

The system allows the owner/user to make assumptions regarding the many variables affecting the cost of a piece of equipment. It must be appreciated that the ACTUAL overall costs will not be known until the day the piece of equipment is actually sold or scrapped (*IF* adequate records have been kept throughout the equipment ownership). Costing therefore depends on good record keeping and a realistic appreciation and assessment of a range of important historical, current and future factors.

The system intends to highlight the real costs of financing and ownership which are neglected in many equipment management systems, and which can dwarf operating costs in a high-cost-finance environment; thus possibly adversely affecting management decisions on choice of technology or equipment. Costs are particularly sensitive to annual utilisation as Tables A & B show. Whereas many equipment items are designed to achieve annual utilisation of 1,000 to 1,500 hours of work for economic ownership, significantly lower utilisation can be extremely expensive and un-economic. The system demonstrates that for most roadworks in developing countries the operating environment is particularly unfavourable to the use of sophisticated plant.

The costing system should allow contractors to quickly assess the affects of various assumptions or scenarios and how this will affect their income, outgoings and profits.

For Figure 7 the costing system has been used to compare the costs of a 120 hp motorgrader with a 100 hp 4WD agricultural tractor and heavy towed grader. Both machines are capable of similar physical performance as demonstrated by the *Roads 2000* project in Kenya (Reference 19). The motorgrader hourly physical output is expected to be some 20% higher than the tractor and towed grader combination, however the higher availability and flexibility of tractor use should allow higher utilisation and therefore much lower unit work costs.

For the Annex 2 calculation example the following assumptions were made:-

ASSUMPTION	MOTORGRADER	TRACTOR + TOWED GRADER
Finance Interest Charge	20% per annum	20% per annum
Purchase Cost assumed in Tables A & B	US\$ 200,000	US\$ 90,000
Actual Purchase Cost (adjustment)	US\$ 195,000	US\$ 88,000
Economic Life	12 years	10 years
Annual Utilisation (hours)	600 (eg 100 days @ 6 hours)	800 hours

Other Annual Utilisation assumptions were used to plot Figure 7.

ANNEX 3 - MANUFACTURER'S DETAILS

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