Labour-based Technology
A Review of Current Practice

PAPERS OF THE SIXTH REGIONAL SEMINAR

Theme of the seminar:
The Right Tool for the Job — A Review of Tools and Equipment for Labour-based Infrastructure Works

Compiled by
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Abbreviations and acronyms

4WD Four wheel drive
ADENA Agencia National de Despacho, Mozambique
APP Affirmative Procurement Policy
ATU Appropriate Technology Unit
BPWA British Public Works Association
CBR California Bearing Ratio
CF Compaction Fraction
CIDA Canadian International Development Agency
CIF Carriage in Freight
CROF Clean Report of Findings
CSIR Centre for Scientific and Industrial Research
DANIDA Danish International Development Authority
DCP Dynamic Cone Penetrometer
DEP Provincial Department of Roads
DFID Department For International Development (formerly ODA)
DGIS Directorate General for International Co-operation
DN Dynamic Cone Penetrometer Number
DNEP National Directorate of Roads and Bridges
DoW Directorate of Works
DPOPH Provincial Directorate of Works, Mozambique
EAMAT Eastern Africa Multidisciplinary Advisory Team
EBT Equipment-based Technology
ECMEP Enterprise for the Construction and Maintenance of Roads and Bridges, Mozambique
EDCs Economically Emerging and Developing Countries
EFT Earliest Finish Times
EST Earliest Start Times
ETB Emulsion Treated Base
EU European Union
FIT Farm Implements and Tools
FRP Feeder Roads Project
GEMs Gravel Emulsified Mixes
IFAD International Fund for Agricultural Development
ILO International Labour Organisation
KiW Kreditanstalt für Wiederaufbau
LB Labour Based
LBT Labour-based Technology
### Abbreviations and acronyms (continued)

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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>LFT</td>
<td>Latest Finish Times</td>
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<tr>
<td>LST</td>
<td>Latest Start Times</td>
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<td>MART</td>
<td>Management of Appropriate Road Technology</td>
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<td>MDD</td>
<td>Maximum dry density</td>
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<td>MoW</td>
<td>Ministry of Works</td>
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<td>MRP</td>
<td>Minor Roads Programme</td>
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<td>NGO</td>
<td>Non-Government Organisation</td>
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<td>NHBRC</td>
<td>National Home Builder’s Registration Council</td>
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<td>NORAD</td>
<td>Norwegian Agency for Development Co-operation</td>
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<td>OMC</td>
<td>Optimum moisture content</td>
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<td>PAMU</td>
<td>Procurement Advisory Monitoring Unit</td>
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<td>PIARC</td>
<td>World Road Association</td>
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<td>PIs</td>
<td>Plasticity Indices</td>
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<td>PRE</td>
<td>Provincial Road Engineer</td>
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<td>R&amp;M</td>
<td>Rehabilitation and Maintenance</td>
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<td>ROCS</td>
<td>Roads and Coastal Shipping Project</td>
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<td>ROPS</td>
<td>Roll Over Protection Structure</td>
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<td>SABITA</td>
<td>Southern African Bitumen and Tar Association</td>
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<td>SABS</td>
<td>South African Bureau of Standards</td>
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<td>SADOT</td>
<td>South African Department of Transport</td>
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<td>SAMAT</td>
<td>Southern Africa Multidisciplinary Advisory Team</td>
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<td>SCC</td>
<td>State Construction Corporation</td>
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<td>SDC</td>
<td>Swiss Development Co-operation and Humanitarian Aid</td>
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<td>SDFs</td>
<td>Social Development Funds</td>
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<td>SIDA</td>
<td>Swedish International Development Authority</td>
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<td>SMLC</td>
<td>Southern Metropolitan Local Council</td>
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<td>SMMEs</td>
<td>Small, Medium and Micro Enterprises</td>
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<td>t</td>
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<td>TDR</td>
<td>Technology Development and Research</td>
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<td>TRH14</td>
<td>Technical Recommendations for Highways</td>
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<td>TRL</td>
<td>Transport Research Laboratory</td>
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<td>ULI</td>
<td>User Led Innovation</td>
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<tr>
<td>USAID</td>
<td>United States Agency for International Development</td>
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<tr>
<td>UST</td>
<td>University of Science and Technology</td>
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<tr>
<td>UTRP/FRC</td>
<td>Uganda Transport Rehabilitation Programme/Feeder Roads</td>
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1 EMPLOYMENT AND INFRASTRUCTURE
1.1 THE ILO AND EMPLOYMENT-INTENSIVE INFRASTRUCTURE POLICIES AND PRACTICES

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The Copenhagen World Summit for Social Development undertook, among other items, to expand work opportunities and productivity in both rural and urban sectors in developing countries by investing in human resource development, promoting technologies that generate productive employment and by encouraging self-employment, entrepreneurship and small- and medium-sized enterprises. The Summit’s Programme of Action states that labour-intensive investments in infrastructure should be encouraged and lays emphasis on the creation and growth of private sector enterprises, the removal of obstacles faced by small and medium-sized enterprises and facilitating their access to credits, markets, training and technology. Labour standards and social protection should be progressively extended to the informal sector without destroying its ability to generate employment. The ILO's Employment-Intensive Programme is discussed in this context.

1.1.1 What is the Employment-Intensive Programme?

The Employment-Intensive Programme (EIP) was created in the mid 1970s as part of the ILO's response to the deteriorating employment situation in developing countries. Its principal objective is to influence infrastructure investment policies so that they have a greater impact on employment creation and poverty alleviation. In most developing countries, a high percentage of government investment budgets as well as gross fixed capital formation is allocated to infrastructure creation and maintenance. By demonstrating how such infrastructure can be created and maintained in a cost-effective manner with labour-intensive methods, the programme has a major impact on creating sustainable employment with available existing resources. Furthermore, by influencing such investments towards the needs of low-income groups, the programme has a double impact on poverty alleviation, both through the infrastructure itself, and through the employment created during construction and maintenance. By the end of 1996, 25 EIP country programmes were operational, representing some 70 different projects, among which were 8 regional projects.

1.1.2 How did the Programme Evolve?

The EIP originated from two different programmes and approaches to employment-intensive works. The first were the "Special Public Works Programmes", which were essentially emergency employment schemes; ILO controlled both the management and investment funds for these schemes. The second focused on changing the technological approach to infrastructure
development and maintenance by technical ministries from a capital-intensive to a labour-intensive one, through pilot demonstration work and capacity building.

Following the merger of these two programmes, the EIP has evolved into a programme which is concerned with long-term sustainable development through the cost-effective use of local resources for infrastructure development and maintenance. It no longer deals with Special Public Works Programmes. Emergency employment work is only considered in special situations (e.g. Somalia, Cambodia, Gaza) but always with a long-term perspective and by incorporating elements which contribute to sustainability. Its principal means of action is capacity building at various levels in both public and private sectors. The programme has acquired a very good reputation with governments and funding agencies such as the World Bank, who acknowledge the ILO as a leader in this field. EIP country projects now provide excellent opportunities of creating a multi-disciplinary approach to job creation in close collaboration with other ILO programmes, e.g. those dealing with vocational training, enterprise development and co-operatives. They also provide good entry points to promote ILO principles and relevant labour standards.

1.1.3 Why Does the ILO Carry Out Such a Programme as Part of its Regular Work? Where is the ILO’s "Added Value"?

The EIP responds to the needs of workers in the unorganised sectors as well as to the unemployed. The programme brings not only employment to these workers, but also helps to establish domestic construction industry capacities by developing small enterprises, who are able to apply employment-intensive construction and maintenance methods. EIP-supported projects provide a unique opportunity of introducing, on an incremental basis, a number of ILO’s fundamental social standards, for example, through developing and introducing contract documentation with appropriate clauses relating to minimum age, minimum wage, non-discrimination and work insurance. Technical training programmes provide opportunities to discuss and introduce these subjects with employers and Government Agencies.

At community level, whether in the urban or rural informal sectors, basic infrastructure investments go a long way to improving the working and living conditions of the poor. The programme promotes democratisation at the grassroots level by helping people to (i) organise themselves and (ii) negotiate with public authorities for a greater share of and control over national infrastructure investment resources. The programme provides, therefore, a practical contribution to the ILO’s three priority objectives of poverty alleviation, protection of workers and democratisation.

The programme is also helping develop university curricula to promote labour-based technologies and to introduce concepts of technology choice. Other training programmes are geared towards worksite supervisors, community associations and public officials responsible for tendering and contracting. In addition, the employment-intensive programme undertakes joint activities with ILO’s work on the urban informal sector, women in development, the environment and co-operative development.
1.1.4 Who are the Principal Partners of the EIP?

Not only government agencies but also employer and worker organisations and the international community have interests in this field. The programme provides Ministries of Labour with a practical and policy tool with which to convince Finance, Planning and Technical Ministries - as well as municipal and local government authorities - of the importance of employment creation and social protection.

Furthermore, the programme supports workers in unorganised sectors in their efforts to organise themselves and to negotiate for a more substantial participation in the national development process. For example, in the case of South Africa, the original request for ILO assistance in the framework of the country's National Public Works Programme came from the COSATU workers’ confederation. Associations of informal sector workers, community contractors and local development committees are some of the groups through which the workers' movements can reach out and extend their membership and social initiatives to workers in the unorganised sectors.

Finally, the programme is an instrument for employers’ associations to become partners in generating new sources of employment through the involvement and development of small enterprises in the private sector. By training small-scale contractors in the use of labour-intensive approaches, the employment-intensive programme creates a new partnership between employment creation and domestic construction industry development. ILO-supported small contractor training programmes in Ghana, Lesotho and Zambia have resulted in the creation of associations of labour-based contractors.

1.1.5 What is the Future Orientation of the Programme?

More effort will go into strengthening relations with Labour Ministries and employers’ and workers’ organisations, with a view to defining jointly how best the unorganised workers and small-scale employers can be served by existing national institutions. The potential for developing labour legislation models for non-organised workers will also be explored.

Another area which will be more systematically emphasised is the integration of ILO principles and standards into new training materials and guidelines aimed at the private sector, government agencies and donors. As the programme evolves, an increasing number of tasks, such as the provision of technical support and training, can be transferred or subcontracted to other partners, including beneficiary governments, private consulting firms, international development organisations and NGOs. The ILO will then increasingly be able to concentrate on ensuring that employment-intensive approaches are adopted on a nation-wide scale and that its policies and principles are applied. This implies that the ILO should invest in training and briefing other actors in a systematic manner.

1.1.6 Programme Activities

The type of work undertaken by the EIP consists of:
• technical co-operation, developing new methodologies and providing guidance to governments, donors and relevant organisations and institutions in the implementation of selected, innovative projects.
• formulating general policy and technical guidelines and strategy documents for the promotion and establishment of employment-intensive approaches.
• carrying out studies and analyses of different aspects of employment-intensive works.
• preparing country-specific policy papers, technical studies and guidelines.
• organising and conducting policy and technical seminars.
• developing and testing material for training courses on employment-intensive approaches.

1.1.6.1 Road sector

In this sub-sector, the EIP is involved with technical co-operation projects in some 20 countries, mainly in Africa.

The work includes further development of labour-based road technology, in particular regarding the establishment of a domestic public and private sector capacity for this type of work, the choice of appropriate tools and equipment and the introduction of appropriate policies and related systems and procedures.

Its current focus is the development of domestic small-scale contractors able to execute labour-based works and, in parallel, the establishment of administrative and financial procedures enabling such contractors to compete for and execute public works contracts.

Collaboration with universities in both developed and developing countries has been established with the objective of developing training modules on labour-based road works and integrating these into universities and other training institutions' course materials.

An ILO regional programme of Advisory Support, Information Services and Training (ASIST) in sub-Saharan Africa provides technical backstopping services and advice on technical, organisational and management aspects of labour-based road works, develops and conducts international courses, seminars and study tours, and collects and disseminates information to organisations involved in employment-intensive works. ASIST is mainly concerned with road construction and maintenance, but its mandate also covers rural transport activities and urban infrastructure works. The ILO is currently developing and negotiating similar support programmes in Asia and the Pacific, and in Francophone West Africa.

1.1.6.2 Rural transport

In the beginning of the 1980s it was increasingly recognised that the investment in roads and motorised vehicles in developing countries did not have the intended impact in alleviating the transport needs of rural households. Surveys undertaken on rural transport needs and demand revealed that most transport in rural areas takes place off the road and on foot, and that the vast majority of the transport burden is related to domestic activities and carried out by women. The EIP rural transport component considers a wider scale of transport interventions, based on comprehensive surveys of rural household transport needs, and including
interventions on tracks and paths, intermediate transport means and transport services to complement roads and transport by motorised vehicles.

Through field projects, an integrated rural accessibility planning methodology has been developed and tested. This methodology provides a planning tool for local-level planning of infrastructure investment and the production of development plans.

The ILO’s work on rural transport has led to the creation of the International Forum for Rural Transport and Development. This is a global initiative dealing with awareness raising, information dissemination and networking, which acts as a facilitator of work on rural transport.

1.1.6.3 Multi-sectoral works

The ILO’s engagement in multi-sectoral works traditionally concerned the preparation and execution of special public works programmes having a short-term perspective of employment creation. Over the years there has been a shift towards long-term capacity building support for multi-sectoral investment programmes. In line with this development, the role of the ILO has changed from managing investments to the provision of advisory services and technical assistance to large-scale investment programmes. Technical co-operation concerning multi-sectoral works is currently carried out in five countries.

Within the context of the social dimension of structural adjustment, the World Bank has become increasingly involved in the setting up of multi-sectoral public works and employment projects executed by non-government agencies. An example of such an agency in West-Africa is the "Agence d’Exécution des Travaux d’intérêt Public pour l’Emploi (AGETIPE)". The main objective of these Agencies is to create employment through infrastructure works which are subcontracted to the private sector. An issue of concern to the ILO has been the short-term perspective of this approach to infrastructure creation and, as a result, a general neglect of the training, capacity building and sustainable employment promotion elements in this approach. In order to overcome these constraints the ILO collaborates with the World Bank and the agencies concerned in the establishment of a sub-regional initiative to provide technical assistance, training and advisory services.

1.1.7 Recent EIP Work

In 1996 and 1997, programmes of collaboration were established with eight higher educational institutions in Africa and five in Asia, resulting in the incorporation of materials on technological choice and management of employment-intensive programmes into university courses.

Advisory assistance provided to Member States particularly concerned capacity building in the private sector for the implementation of employment-intensive works funded through infrastructure investments by governments, development banks and bilateral donor agencies. The experience in this field is currently being
synthesised into guidelines for programme designers, particularly those concerned with social funds and large scale road sector programmes. Draft guidelines on the management of labour in employment-intensive programmes were prepared, drawing upon experience obtained through advisory work and studies on the application of labour standards in employment-intensive works programmes in Bangladesh, India, Namibia, South Africa and Zambia. The guidelines discuss key issues related to the management of temporary workers in infrastructure projects, emphasising the need for an adapted labour legislation for this category of temporary village workers and the need to promote workers’ rights and conditions of work while safeguarding employers’ interests through appropriate contractual procedures and documentation. These draft guidelines will be discussed and reviewed in a tripartite meeting in Uganda scheduled to take place in October 1997, and are expected to be finalised and published by the end of 1997.

Collaboration with the World Bank continued and resulted in the publication of a World Bank Technical Paper concerning the large scale application of employment-intensive approaches to road works and the establishment of collaboration agreements in the fields of rural travel and transport, and training of public sector agencies implementing employment-intensive infrastructure works through social funds.

Whilst political upheavals created difficulties with employment-intensive technical co-operation projects in Cambodia, Sierra Leone and The Democratic Republic of Congo (previous Zaire), ILO-supported programmes expanded in Ethiopia, Laos, Madagascar, Mozambique and Zambia. Policy and technical advice was provided to an increasing number of countries aiming to establish employment-intensive investment policies and programmes for infrastructure development and maintenance (Botswana, Cambodia, Laos, Lesotho, Malawi, Namibia, South Africa, Uganda and Zimbabwe).

1.1.8 Tools and Equipment

There is significant potential for the local manufacture of well designed, good quality tools and light equipment, which are the principal means of production and quality assurance in labour-based road construction. Too many projects and even large scale programmes continue to underestimate the negative effects of poorly designed and bad quality tools and equipment on productivity and end product. Procurement should primarily be guided by considerations of quality and

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1 Summary guidelines on labour-based road contracting: Project formulation and implementation, ILO (in preparation).
2 Guidelines for labour management in labour-based infrastructure works, ILO (in preparation).
appropriateness of design, rather than only costs as is happening too often. The importance of establishing and introducing appropriate tender and procurement procedures in the context of large scale programmes cannot be over emphasised. Also, the users (whether private or public sector) should be convinced of the productivity gains and large return on investment, when they spend an initially higher amount on the procurement of well designed, good quality items. Given the relatively low proportion of the costs of tools and light equipment as a percentage of the total expenditure and the significant benefits in terms of productivity and durability, both programme managers and contractors stand to gain by ensuring that the right tool is used for the job. From their end local manufacturers should keep themselves informed of the increasing demand for tools and light equipment in this field, and ensure that the quality of the items they produce is adequate to withstand the tough requirements of labour-based construction works.
1.2 THE ROLE OF ASIST

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The Honourable Minister, Permanent Secretary, Ladies and Gentlemen. First of all let me say how pleased I am to have this opportunity to come back to Uganda, and I look forward to catching up on the many developments that are taking place in the country.

I would like to take a very brief look at the role of ASIST in the context of the developments in labour-based technology and in relation to the topic of this seminar -Tools and Equipment. I would like to structure this presentation by looking first at the past developments, then at the present situation, leading to a glimpse into the future.

1.2.1 Past

Many people present are aware of, and have played a role in, the development of the labour-based technology that is in use today. For them this section of the presentation should serve as a reminder of how far we have come. For those more recently involved, I hope it will provide an outline of the background to what is happening today and what we hope to achieve in the future.

(To those who have been active in labour-based works for some time, if my version of history varies from your own, we can argue about it later)

1.2.1.1 Technology and Management

Labour-intensive and labour-based infrastructure has been in use for thousands of years. In the 1970s, ILO began a process of creating a technology and methodology specifically for the use of labour-intensive techniques in rural road construction.

A great deal of effort was put into developing suitable designs, setting out techniques, work organisation, and training of particularly site level staff to carry out the works efficiently and effectively to produce an acceptable finished product. A refined system was created which used simple and manageable steps to produce gravel roads of good quality based on the capabilities of trained foremen and supervisors.

With efforts being concentrated on the organisation and use of labour, equipment tended to be given second priority. As programmes developed, several problems emerged with regard to tools and equipment.

1.2.1.2 Tools and Equipment

Recognising this problem, a guide to tools and equipment was developed. In spite of this guide being produced, hand tools tended to be borrowed directly from the agricultural sector and these proved inadequate for the materials used in road construction and the extensive usage compared with the agricultural sector. (Indeed, many hand tools produced for agriculture are still being used today,
unmodified for road works.) Problems were also encountered with agricultural tractor hitches, trailer drawbars and trailer chassis and bodies.

- The availability of appropriate equipment for the labour-based road sector was fairly limited.
- There was little knowledge among practitioners about appropriate and alternative plant.
- Innovations were taking place on a project by project basis in relative isolation. Although some of the experiences were documented, there was no pro-active dissemination of this information. (In some cases solutions were dependent on local conditions and as a result not necessarily transferable).

Having briefly outlined some of the problems labour-based practitioners were facing in specifying and developing tools, I would like to move on and look at developments in the recent past.

1.2.1.3 Developments

There have been many contributions to the development of better equipment and better specifications for tools and equipment. This includes many people here today as well as colleagues in ILO, partner countries, and consultants. There has also been a recognition that the inclusion of mechanical engineers in finding solutions is essential. Provided they are fully briefed as to what function the equipment will serve, innovative solutions can be found in partnership with labour-based practitioners. After all, we would not expect to see the mechanical engineers out there building the roads; therefore we as road builders should recognise their expertise in designing and developing equipment.

As far as developments go, we now have more readily available the specifications for appropriate hand tools. Despite this, there are still many challenges relating to production of improved tools, sourcing of improved tools, and not least of all procurement. It is evident that these issues still have a significant influence on the productivity experienced in labour-based roadworks.

Trailer designs and details of improved tractor hitch arrangements have also been made available. I think it is fair to say that the application of improved designs for equipment seems to be more often applied than those for hand tools

1.2.2 Future

Looking towards the future, there have been recent shifts in emphasis with relation to labour-based roadworks and recent expansions into new areas. These will fuel a need to intensify research, development and dissemination on appropriate tools and equipment. I would like to highlight some of the specific areas:

- There is a general move towards privatisation and the use of emerging or labour-based contractors, especially for periodic and routine maintenance. With this shift of emphasis comes the need to re-examine tools and equipment from the point of view of the small scale contractor who has to run a commercially viable business.
- With the extension of labour-based technology from rural to minor to more major roads, combined with the scarcity of natural surfacing materials in some areas, use of labour-based techniques for alternative road surfacing and for paved roads is expanding. With this expansion comes the need for
development and dissemination of information on appropriate tools and equipment as mentioned before.

- Attention is focusing on the lack of infrastructure in many planned and unplanned areas of the region’s cities and towns. Labour-based techniques applied to the provision of infrastructure in the urban setting can create appropriate and affordable community services while providing badly needed employment opportunities. Are tools employed for rural works the best solution for urban works?

- Social development funds/Community-based programmes: Not only in the urban sector, but also in the rural areas, social development funds are being implemented with the dual aim of providing assets and creating employment. This demands the application of labour-based techniques to a wide range of infrastructural developments leading to a more multi-sectoral application of labour-based methods. Perhaps many of the experiences that have been gained in labour-based management and appropriate tools, equipment and technologies can be adapted from the roads sector to meet these challenges.

- Multi-sectoral application of labour-based techniques.

1.2.3 Role of ASIST

How does ASIST fit into all that has been presented here? ASIST III has been given an extended mandate for a three year period. For those of you who are not familiar with it, I will briefly mention the areas of focus of ASIST.

- Advisory support provides services related to technical, organisational and management aspects of labour-based projects in 14 countries in the region. In this work, ASIST liaises closely with the ILO multi-disciplinary teams in Harare (SAMAT) and Addis Ababa (EAMAT).

- Information services gather and synthesise general and specific information to disseminate to practitioners, institutions, and other interested parties.

- Training develops and implements in close collaboration with Kisii Training School in Kenya, international courses for engineers, managers, and senior technicians, and assists in setting up courses within national education and training institutions.

Rural travel and transport: Within the framework of ASIST is a Rural Travel and Transport Project which goes beyond the confines of labour-based construction and maintenance, to consider access as a whole and the different types of interventions which aim to remove access and transport constraints. Using integrated rural transport planning, accessibility needs can be identified and prioritised and a structured approach to solving common access problems developed. The resulting interventions may be in the form of improved tracks, paths, bridges, or non-motorised transport, or the improvement and relocation of services, i.e. water supply improvement.

What is perhaps most important to bring forward today, is that a lot of information is now being made available through the ILO-ASIST documentation centre, and the available data base. The Technical Enquiry Service was set up with the collection and dissemination of information as its main purpose. There is now, as a result of this information exchange, an increased interest in sharing experiences and undertaking development work on the part of different agencies, ministries and other actors.
There are a number of guidelines and technical briefs already developed or in the process of being developed. Although progress is being made, I feel sure that the next few days of discussion will highlight many remaining challenges in the specification, procurement and maintenance of equipment and tools.

1.2.4 ASIST III Outputs

- Improved information and knowledge available about labour-based methods in rural and urban environments.
- Labour-based methods promoted and supported in priority sectors in rural and urban areas.
- Skills and know-how on labour-based methods acquired by key actors.
- Labour-based advisory, information, and training services institutionalised.
- Standards and conditions for workers on labour-based projects, applied in line with ILO “Conventions and Recommendations”.
1.3 INFORMATION TECHNOLOGY DEVELOPMENTS — HOW THEY AFFECT ASIST’S SERVICE TO YOU, OUR CLIENTS

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1.3.1 What Information is on Offer?

What information sources have we to offer you?

- Written, researched replies to technical queries, free of charge.
- Published textbooks and reports (e.g. from ILO, IT Publications, World Bank, etc.), at cost.
- Photocopies of unpublished and out-of-print material, at cost.
- Videos of labour-based works, and rural travel and transport, at cost.
- Technical Briefs, Working Papers, Reports, Training Material produced by the ASIST team, at cost.
- A full catalogue of all the documents we have available for distribution, on diskette, called ASISTDOC, at cost.
- A Source Book of key documents, free on application.

1.3.2 How Do We Get This Information To You?

1.3.2.1 When we started...

When we started, you communicated with us by:

- post
- telephone
- fax
- telex

and we replied for:

- messages, by post, phone, fax, telex
- documents, by post, and sometimes fax (if they were short), and by DHL (if they were urgent).

Nowadays...

These days, we see that most of our corporate clients have a fax machine. However, many of our individual clients still rely on the post. Hardly anybody uses a telex machine, so we have closed our telex down. These days, we also see that more and more of our clients use e-mail.
With e-mail you can:

- send messages
- attach documents as computer files.

### 1.3.3 What is E-mail?

E-mail is a system for sending electronic messages. It works just like the normal mail system. You post your message. It is collected by the post office and delivered to the person you have addressed it to.

The difference from the normal mail (now called snail mail) is that you type the message on your computer. Then you dial up your post office and send the message down the telephone line to the postmaster. This postmaster is not a person but another computer. The postmaster computer looks at the address and sends it by telephone line around the world from computer to computer until it arrives at the post office your colleague subscribes to. Then when your colleague next calls into his post box, he gets your message.

The added advantage of e-mail is that you can attach an electronic document, like a report, to your message, just like you could physically post it together with your letter. You can also send faxes by e-mail.

#### 1.3.3.1 How can you access Email?

What do you need to access email?

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Personal Computer (a 486, or a Pentium)</td>
<td>$2000</td>
</tr>
<tr>
<td>A telephone line</td>
<td>$3 per month</td>
</tr>
<tr>
<td>A modem (to connect the computer to the telephone line)</td>
<td>$100</td>
</tr>
<tr>
<td>A suitable operating system (Microsoft MS-DOS 6.x, Windows 3.x, Windows 95, Windows NT)</td>
<td>Free with computer</td>
</tr>
<tr>
<td>An E-mail Service Provider (a company to link you by telephone to the world-wide e-mail network)</td>
<td>$10 to $15 per month</td>
</tr>
<tr>
<td>E-mail software (FrontDoor, Eudora, Microsoft Internet Explorer)</td>
<td>Free from your service provider</td>
</tr>
<tr>
<td>Training in how to set up and use the software</td>
<td>$50</td>
</tr>
</tbody>
</table>

### 1.3.4 What is the Internet?

It is a network of computers around the world.

People and companies store information on these computers. Anybody can connect to them and access this information.

The computers are connected together like a spider’s web. They are sometimes referred to as the World Wide Web. And each person or company’s piece of information within this web is called a Web Site. The Internet is also used to send and receive e-mail messages and attached documents.
1.3.4.1 How can you access the Internet?

What do you need to access the Internet?

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Personal Computer (a 486, or a Pentium)</td>
<td>$2000</td>
</tr>
<tr>
<td>A telephone line</td>
<td>$3 per month</td>
</tr>
<tr>
<td>A fast modem (to connect the computer to the telephone line)</td>
<td>$200</td>
</tr>
<tr>
<td>A suitable operating system (Microsoft Windows 3.x, Windows 95, Windows NT)</td>
<td>Free with computer</td>
</tr>
<tr>
<td>An Internet Service Provider or ISP (a company to link you by telephone to the Web)</td>
<td>$50 to $100 per month</td>
</tr>
<tr>
<td>Internet software (Netscape, Microsoft Internet Explorer)</td>
<td>Free from ISP</td>
</tr>
<tr>
<td>Training in how to set up and use the software</td>
<td>$50</td>
</tr>
</tbody>
</table>

Note: if you subscribe to an ISP, you will get e-mail thrown in for free

1.3.5 The ASIST Web site

Address: http://iloasist.csir.co.za (Hypertext Transfer Protocol)

1.3.5.1 What can you do when connected to the Web Site?

Broadly:

- Browsing
- Downloading
- E-mailing

Browsing

This means searching for information while you are connected to the Web, and viewing the information on your computer screen. You can also print what you see on your screen to your own printer.

Downloading

This means copying the information you are interested in from the Web Site to your own computer. You can then edit it and print it as you wish.

E-mailing

This means sending your comments or order to the Web Site author by e-mail.

1.3.5.2 What will the ASIST Web Site offer you?

- ASISTDOC to browse, to select documents you are interested in, and to send an e-mail order. You can also download your own personal copy of the database
- Background information on the ILO, ASIST, and their projects and programmes, for you to browse, and to download
- Key documents (non-copyrighted) in full text. Only a few documents are available at the moment, but more and more are being added each month.
Note: you may have some difficulty using downloaded files if the software you have is not compatible with the original files.

1.3.5.3 What if you don't have an Internet connection?

- Everything that is on the Web Site will also be available on a CD-ROM.
- Alternatively, individual files can be attached to e-mail messages to you.
- Alternatively, individual files can be sent to you on diskette.
- Alternatively, you can still get hard copies by post.

Summary

<table>
<thead>
<tr>
<th>If you have</th>
<th>then</th>
</tr>
</thead>
<tbody>
<tr>
<td>No computer</td>
<td>“hard copy” information can be posted to you</td>
</tr>
<tr>
<td>A simple computer</td>
<td>documents can be sent to you on diskette, if available in electronic form</td>
</tr>
<tr>
<td>A CD-ROM</td>
<td>documents can be sent to you on CD-ROM, if available in electronic form</td>
</tr>
<tr>
<td>An e-mail connection</td>
<td>documents can be sent to you as attached files, if available in electronic form</td>
</tr>
<tr>
<td>An Internet connection</td>
<td>you can browse the Web Site and download the documents to your computer, if available in electronic form</td>
</tr>
</tbody>
</table>

1.3.6 Postscript: The ILO Pouch System

Is there a UNDP office near you? If there is, then you could possibly make an arrangement with them to receive documents from us through the diplomatic pouch system. Check it out.
1.4 MOBILISING THE PRIVATE SECTOR TO ENGAGE IN LABOUR-BASED INFRASTRUCTURE WORKS: A SOUTH AFRICAN PERSPECTIVE

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1.4.1 Introduction

Organs of state (in the national, provincial or local sphere of government) are responsible for the provision of public infrastructure including roads. The construction of infrastructure can either be undertaken by utilising in-house resources (force-account) or by outsourcing to the private sector (procurement). Public expenditure in the infrastructure sector, as with any other sector of the economy, will generate employment opportunities. The total number of employment opportunities and who derives benefit from such employment opportunities depends upon how a construction project is structured.

In force account operations, an organ of state has direct control over the outcome of a construction project. When outsourcing, its control is diminished. This paper is concerned with the outsourcing of work to the private sector.

The Green Paper on Public Sector Procurement Reform in South Africa (1997) suggests that procurement can facilitate the generation of jobs in South Africa by:

- ensuring that the foreign content in contracts involving goods, services and works is minimised;
- encouraging the substitution of labour for capital;
- supporting the use of “labour friendly” technologies which utilise a higher degree of labour input than is the case work conventional technologies, or are well suited to implementation by small scale enterprises; and
- encouraging and developing small scale enterprises to implement employment intensive practices and “labour-friendly” technologies.

1.4.2 Labour-based Construction Technologies

Labour-based methods and technologies have been employed in South Africa on construction projects which include rural gravel roads; low level bridges; small dams; residential township roads (surfaced and gravel); water and sewer reticulation for townships; bituminous surfacing of roads; low voltage electrical reticulations; stormwater drainage systems; and on-site sanitation. Road maintenance projects have included regravelling and routine road maintenance.

Table 1 shows the estimated number of manhours required to service an erf in a low cost township using conventional construction methods. What is immediately apparent from this table is that road work is the most capital intensive activity.
(highest cost / manhour) and therefore the discipline which has the highest potential for increasing employment opportunities. On civil engineering projects of this nature, the cost of materials is generally taken to be 25% of the total construction cost. This being the case, it is apparent from Table 1 that significant increases in employment opportunities can be achieved by examining materials manufacturing methods.

Table 1: Manhours required in the provision of infrastructure for a low cost township using conventional construction methods (Watermeyer and Band, 1994)

<table>
<thead>
<tr>
<th>Service</th>
<th>Estimated manhours (%)</th>
<th>Estimated total number of manhours / ERF</th>
<th>Cost/manhours* (Rand / manhours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>13</td>
<td>87</td>
<td>39</td>
</tr>
<tr>
<td>Sewerage</td>
<td>16</td>
<td>84</td>
<td>43</td>
</tr>
<tr>
<td>Roads</td>
<td>14</td>
<td>86</td>
<td>21</td>
</tr>
<tr>
<td>Stormwater</td>
<td>8</td>
<td>92</td>
<td>26</td>
</tr>
<tr>
<td>Electricity</td>
<td>70</td>
<td>30</td>
<td>117</td>
</tr>
<tr>
<td>TOTAL</td>
<td>40</td>
<td>60</td>
<td>246</td>
</tr>
</tbody>
</table>

* Based on March 1992 rates which included P & G but excludes VAT and professional fees.

Labour-intensive methods of excavation can significantly increase the employment potential of the activities shown in Table 1. For example, Watermeyer and Band (1994) have shown that hand excavation of trenches can reduce the cost per manhour in respect of water and sewerage from that tabulated in Table 1 to R14 and R9 / manhour respectively. Watermeyer et al (1995) have found in the upgrading of Soweto’s infrastructure, the following multipliers in employment opportunities (i.e. ratio of average total number of manhours generated in the construction of a specified structure or service using labour-based technologies to that generated in one using plant-based technologies):

- excavate and backfill trenches for water construction 1.9.
- excavate, lay pipes and backfill water reticulation 1.4.
- construct waterbound macadam roads 4.7.
- construct concrete block roads 2.3.

There has been considerable interest generated by the employment potential of roadworks. Table 2 highlights the potential employment which can be generated in road construction.

Table 2: The employment potential of various roadwork activities (Watermeyer and Band, 1994)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Thickness (mm)</th>
<th>Manhours to produce and construct (manhours/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadbed Preparation (R&amp;R)</td>
<td>Plant-based</td>
<td>Labour-based</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Gravel wearing course (G5)</td>
<td>125</td>
<td>0.160</td>
</tr>
<tr>
<td>Gravel wearing course (G4)</td>
<td>150</td>
<td>0.192</td>
</tr>
<tr>
<td>Base course (G4)</td>
<td>150</td>
<td>0.192</td>
</tr>
<tr>
<td>Base course (G3)</td>
<td>125</td>
<td>0.165</td>
</tr>
<tr>
<td>Subbase (G6)</td>
<td>150</td>
<td>0.192</td>
</tr>
<tr>
<td>Waterbound macadam base course</td>
<td>100</td>
<td>1.040</td>
</tr>
<tr>
<td>Slurry</td>
<td>15</td>
<td>0.110</td>
</tr>
<tr>
<td>Asphalt</td>
<td>25</td>
<td>0.140</td>
</tr>
<tr>
<td>Concrete blocks</td>
<td>60</td>
<td>0.930+</td>
</tr>
<tr>
<td>Cast in situ (plastic cell) blocks</td>
<td>-</td>
<td>0.38</td>
</tr>
</tbody>
</table>

+ Factory produced block paving
# Blocks manufactured on site using employment-intensive methods

Potgieter et al (1997), when commenting on recent South African experience in this regard, state that “The cost of big machinery largely prevented micro and small contractors from owning road construction companies. The road construction fraternity made no ingress into creating ownership (empowerment) for small / micro road construction companies long after house building, water pipes, sewer networks etc were done by small independent contractors. It was only after the recent breakthrough in developing pavements that can be constructed without machines that company ownership was put within reach of the small / micro companies (machine purchases below R 15 000 (US$ 3 500 )). ...these pavements are either from the last century before road machines were developed (e.g. Telford, macadams etc) or from modern developments (e.g. Gravel Emulsified Mixes, foamed bitumen etc).”

In South Africa, the following roadwork technologies have been utilised to facilitate labour-based construction by small scale enterprises (Potgieter et al. (1997):

- Telford base and sub-base construction (dump rock of size 75 x 125 x 175mm packed on a prepared level sub-base with smaller stones placed and rammed in with hammers between openings and protrusions broken off by means of hammers. Technique used in the UK at the turn of 18th century).
- dump rock kerbing and verge construction.
- cast in-situ and site manufactured precast concrete kerbing.
- dump rock kerbing with voids between rocks filled with crusher dust cement slurry.
- water bound macadam bases (single size aggregate of 37 or 53mm with a gap grading and virtually no aggregate below 19mm in size, with voids filled with fines. Construction technique pioneered by Macadam in Scotland which replaced Telford construction).
- traditional process where the fines are washed and vibrated into the voids.
• dry bound where the filler “dry flows” into the voids during vibration compaction without the help of any moisture, with or without slurry penetration which fills the top 10 to 25mm of exposed aggregate
• slurry bound (penetration Macadam developed in 1907 where the large aggregate base was filled by hand with hot bitumen or tar binder and later by mechanical sprays. Potgieter et al, (1995 and 1996) developed a cold bitumen process.)
• composite Macadam (a water bound or dry bound Macadam base with a top layer of smaller coarse aggregate (typically a natural gravel) laid as a thin slurry bound Macadam acting as a durable key-in layer.)
• roller compacted concrete (dry-mix concrete produced from a continuously graded crushed stone).
• Gravel Emulsified Mixes (GEMs) (the modification of medium to marginal quality natural gravel with the addition of 2-3% emulsified bitumen, 1-2% of cement and sometimes 1-2% lime.)
• foamed bitumen (foamed bitumen is mixed in with aggregate and thereafter constructed in a layer as is the case for a natural gravel).
• dust palliatives.
• interlocking block paving
• precast concrete block paving
• plastic cells (with concrete or slurry bound Macadam)

Technologies for ancillary works have included:
• plain and reinforced masonry drainage structures (Watermeyer, 1992).
• rubble masonry bridges (Rankine et al. 1995)

Not all of the above mentioned roadwork technologies have been successful as some communities have rejected their finished appearance and / or poor riding quality.

Changes in methods and technologies, which increase the labour content in construction and in the manufacture of materials, yield the greatest increase in the number of employment opportunities generated per unit of expenditure. This requires well established companies to change their work methods and to reduce their reliance on capital intensive technologies. Such methods and technologies are usually readily implemented by small scale enterprises, who by being small, have limited access to capital and invariably operate and conduct their business in a more employment-intensive fashion and favour light equipment-based forms of construction.

1.4.3 Implementing Labour-based Projects

In force account works, the true cost of construction is seldom known as records invariably only reflect the cost of outsourced items viz., materials and labour. (The supervision, plant, establishment costs etc are invariably absorbed in the overall running cost of the organ of state and are seldom separated out.) When outsourcing works in their entirety, the construction cost is very visible as it is simply the contract cost. (Ancillary costs e.g. professional fees and administration costs, are usually costed as a percentage of the construction cost.)
The tendering / contracting system permits organs of state to gather statistics on the cost of labour-based works and plant-based works. Comparisons are inevitable. Many of the aforementioned technologies, although being effective in generating increases in the total quantity of employment on a project, are very inefficient when the expenditure per unit of employment is considered. As a result, many labour-intensive techniques and technologies are simply not viable or justifiable. In South Africa, there is a constitutional requirement (section 217 of the Constitution of the Republic of South Africa) for organs of state to procure goods and services in accordance with a system which is fair, equitable, transparent, competitive and cost effective.

The choice of technology is generally made during the basic design phase of works contracts, whereas the choice of construction method / method of manufacture is usually decided upon during the construction phase. Two alternative approaches to implementing labour-based works can be adopted.

**Method 1**: lay down the use of specific employment-intensive technologies and methods of construction / manufacture in the contract document.

**Method 2**: afford tenderers the opportunity to choose the technology / construction method / method of materials manufacture which they wish to use in order to implement employment-intensive methods and to reward them for the degree to which they embrace such technologies.

Either method may be used to increase the quantity of employment generated per unit of expenditure. Method 1 usually achieves the objective by restricting the use of certain types of plant / manufacturing methods and by specifying particular technologies. Method 2, on the other hand, requires tenderers to tender the amount of labour, which they undertake to engage in the performance of the contract and to be rewarded at tender stage for this. Method 2, accordingly, permits tenderers to use their knowledge, skill and creativity in arriving at an optimum economic mix of equipment, technologies and labour in order to meet their obligations e.g., a tenderer on a roads contract may choose to manufacture kerbs and precast concrete components on site rather than to excavate the box cut for the road by hand in order to provide employment for a target group.

Method 1 is well suited to the targeting of local labour. The economic viability of this approach is, however, dependent on the ability of the designer / specifier to forecast cost. Method 2 can be used for the employment of relatively unskilled labour and any potential price premium can be readily assessed during the adjudication of tenders. Method 2 therefore has the distinct advantage that tender prices will usually fall within acceptable limits and economic justification of decisions relating to employment generation will not be necessary. Method 1 runs the risk that tenderers may out price some technologies which don’t suit their companies in an effort to dissuade an organ of state from utilising certain labour-based technologies.

What is also required is a strategy to engage small, medium and micro enterprises in a cost effective manner as these enterprises are most likely to implement labour-based technologies. An approach which forces the private sector to embrace labour-based technologies in order to secure a competitive advantage over their competitors is one which is likely to succeed.
The remainder of this paper will examine the tools required to engage the private sector in labour-based infrastructure works viz.:

- appropriate specifications.
- contract strategies.

### 1.4.4 Specifications

SABS 0120: Part 1 defines a specification as a technical description of the standards of materials and workmanship that the contractor is to use in the works to be executed, the performance of the works when completed, and the manner in which payment will be made.

There is considerable merit in separating payment from specifications. For the purposes of this paper, however, payment methods will be linked to specifications.

Specifications are an important tool for securing and administering labour-based methods and technologies in infrastructure works contracts. Some aspects which need to be addressed in specifications are reviewed by way of examples.

#### 1.4.4.1 Earthworks specifications

Any earthworks specifications for labour-based earthworks activities, irrespective of whether or not they are a modification of a standardised specification such as SABS 1200, should, inter alia, address:

- the manner in which material is to be excavated/compacted.
- the degree of compaction required.
- testing requirements.
- how the work is to be measured and paid for.

#### 1.4.4.2 Excavation

Labour-based excavation practices can be implemented by restricting the use of plant permitted on the contract and only using plant in exceptional circumstances. Generally plant is required when the depth of excavation becomes unmanageable or excessive, ground conditions are adverse or the material to be excavated becomes too hard for economic removal by means of hand tools.

Simple clauses can be included in earthworks specifications to permit the use of plant where excavation depths become unmanageable, e.g., 2.0 m deep trenches or where adverse ground conditions exist, e.g. below the water table. The challenge, however, is to produce an appropriate and workable earthworks classification which will enable engineers, in the first instance, to identify projects which are eminently suitable for labour-based construction methods and, secondly, to administer contracts where labour-based earthworks practices are employed.

SABS 1200 D classifies earthworks as being one of five categories, viz. soft, intermediate, hard rock, boulder class A and boulder class B. Boulder class excavation is classified in terms of the size and volume of boulders contained in the soil matrix whereas the classifications for soft, intermediate and hard rock are in terms of the capabilities of specific items of plant as set out in Table 3. In terms of the specification, the engineer decides on the classification of the material based on a visual inspection and the criteria set out in Table 3. In the event that a
disagreement arises between the contractor and engineer, the contractor is responsible for making available at his cost the plant referred to in Table 3 in order to assess the reasonable removability or otherwise of the material. The engineer then decides whether or not the specified plant can efficiently remove or rip the material in question whereupon his decision shall be final and binding.
### Table 3: SABS 1200 D earthworks classification (SABS)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Restricted excavation</strong></td>
<td></td>
</tr>
<tr>
<td>Soft</td>
<td>Material which can be efficiently removed by a back-acting excavator of fly wheel power &gt; 0.10 kW for each mm of tined-bucket width.</td>
</tr>
<tr>
<td>Intermediate</td>
<td>Material which can be removed by a back-acting excavator having a fly wheel power &gt; 0.10 kW for each mm of tined-bucket width or with the use of pneumatic tools before removal by a machine capable of removing soft material.</td>
</tr>
<tr>
<td>Hard Rock</td>
<td>Material that cannot be removed without blasting or wedging and splitting.</td>
</tr>
<tr>
<td><strong>Non-restricted excavation</strong></td>
<td></td>
</tr>
<tr>
<td>Soft</td>
<td>Material which can be efficiently removed or loaded, without prior ripping, by any of the following plant:</td>
</tr>
<tr>
<td></td>
<td>• a bulldozer or a track type front end loader having an approximate mass of 22 tonnes and a fly wheel power of 145 kW.</td>
</tr>
<tr>
<td></td>
<td>• a tractor-scraper unit having an approximate mass of 28 tonnes and fly wheel power of 245 kW, pushed during loading by a bulldozer equivalent to that described above.</td>
</tr>
<tr>
<td>Intermediate</td>
<td>Material which can be efficiently ripped by a bulldozer having an approximate mass of 35 tonnes and a fly wheel power of 220 kW.</td>
</tr>
<tr>
<td>Hard Rock</td>
<td>Material that cannot be efficiently ripped by a bulldozer having an approximate mass of 35 tonnes and a fly wheel power of 220 kW.</td>
</tr>
</tbody>
</table>

The SABS 1200 earthworks classification in its very formulation has an element of subjectivity built into it since the definitions for the classes of excavation are dependent on the interpretation of the word "efficiently". Although SABS 1200 D does define "efficiently" as *in a manner that can reasonably be expected of a contractor, having regard to the production achieved*, the engineer is still required to exercise engineering judgement. It is therefore unreasonable to expect that an earthworks specification for labour-based construction practices will be devoid of all subjectivity.

Coukis (1983) in a World Bank publication has produced some guidelines on the determination of rates of productivity which may be expected in different types of soils. This information is reproduced in Tables 4 and 5. In terms of this classification, materials are firstly classified as being cohesive or non-cohesive and are thereafter codified in terms of a field recognition test, unconfined compressive strength and liquidity index. (The liquidity index equals the quotient of the natural water content minus the plastic limit and the liquid limit minus the plastic limit). Once the material code is known, the expected rates of production...
can be determined for standard conditions from Table 5. (Standard conditions relate to situations which have fair to average site management and low to average incentives for workers. Actual production may vary from 0.25 to 4 times the standard productivity. The productivity data assume that two-thirds of an eight hour day is actually spent working.)

Table 4: Earthworks classifications (Coukis, 1983)

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Field recognition test</th>
<th>Unconfined compressive strength (kN/sq m)</th>
<th>Liquidity index</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Soft</td>
<td>Easily moulded in the fingers</td>
<td>25 to 50</td>
<td>0.7 to 1.4</td>
</tr>
<tr>
<td>3</td>
<td>Firm</td>
<td>Can be moulded in the fingers by strong pressure</td>
<td>50 to 100</td>
<td>0.2 to 0.7</td>
</tr>
<tr>
<td>4</td>
<td>Stiff</td>
<td>Cannot be moulded in the fingers</td>
<td>100 to 200</td>
<td>-0.1 to 0.2</td>
</tr>
<tr>
<td>5</td>
<td>Very stiff</td>
<td>Brittle or very tough - crowbar useful for hand digging</td>
<td>200 to 400</td>
<td>-0.3 to-0.1</td>
</tr>
<tr>
<td>6</td>
<td>Hard</td>
<td>Difficult to dig by hand even with a crowbar</td>
<td>more than 400</td>
<td>less than-0.3</td>
</tr>
</tbody>
</table>

Non-cohesive Soils

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Field recognition test</th>
<th>Relative density</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Very loose</td>
<td>Easily excavated with a shovel</td>
<td>less than 0.2</td>
</tr>
<tr>
<td>3</td>
<td>Loose</td>
<td>Can be dug with a shovel</td>
<td>0.2 to 0.4</td>
</tr>
<tr>
<td>4</td>
<td>Compact</td>
<td>Pick or other swung tool required</td>
<td>0.4 to 0.6</td>
</tr>
<tr>
<td>5</td>
<td>Dense</td>
<td>Crowbar useful for hand digging</td>
<td>0.6 to 0.8</td>
</tr>
<tr>
<td>6</td>
<td>Very dense</td>
<td>Difficult to dig by hand even with a crowbar</td>
<td>more than 0.8</td>
</tr>
<tr>
<td>7</td>
<td>Soft rock</td>
<td>Crowbar and pick required</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 5: Productivity data for excavation by hand (Coukis, 1983)

<table>
<thead>
<tr>
<th>Excavation parameter</th>
<th>Material type</th>
<th>Excavation only</th>
<th>Excavation-loading at given loading height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>Soft/very loose soil</td>
<td>6.7</td>
<td>6.7</td>
</tr>
<tr>
<td>3</td>
<td>Firm/loose soil</td>
<td>4.2</td>
<td>4.2</td>
</tr>
<tr>
<td>4</td>
<td>Stiff/compact soil</td>
<td>3.0</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Very stiff/dense soil</td>
<td>2.4</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Hard/very dense soil</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Soft rock</td>
<td>1.7</td>
<td>-</td>
</tr>
</tbody>
</table>

The World Bank classification and associated productivity rates for the different materials encountered is intended for the planning and management of labour-based programmes. It is, however, not suited to South African contract practices in that it does not allow for excavation by pneumatic tools and the codification of materials requires in certain instances, laboratory testing. Nevertheless, the philosophy behind the classification can be readily translated into a classification for South African conditions.

A South African classification (Soderlund & Schutte, 1994) for labour-based excavation practices is presented in Table 6. This classification makes provision for the excavation by means of a shovel only, a pick and shovel and pneumatic tools. It contains five classes of excavation, three of which relate to excavation by means of hand tools only.

As is the current practice when using SABS 1200 D, the engineer will classify the material on the basis of a visual inspection and his knowledge of expected productivity rates in terms of Table 6. In practice, however, the establishment of the boundaries between soft class 2 and soft class 3, and soft class 3 and intermediate can be highly subjective and the engineer requires a less subjective means of determining the classification of a particular material in the event of a dispute arising. In the event of a disagreement on the classification between the contractor and the engineer, the engineer can be called upon to classify the material in accordance with Tables 7 and 8. Typical rates of production in trench excavation for the soft classes of material are tabulated in Table 9.
S100D specification, on the other hand, also makes use of one parameter, viz. field recognition or in-situ shear strength. The latter method permits labour-based contractors to classify material themselves should they be in possession of a dynamic cone penetrometer (DCP).

**Table 6: Classification of materials (Soderlund & Schutte, 1994)**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft, Class 1</td>
<td>Material which can be excavated by means of a suitable shovel without the use of a pick or other hand swung tool.</td>
</tr>
<tr>
<td>Soft, Class 2</td>
<td>Material which can be readily excavated with the aid of a pick or other hand swung tool.</td>
</tr>
<tr>
<td>Soft, Class 3</td>
<td>Material which can be excavated with difficulty with the aid of a pick or other hand swung tool.</td>
</tr>
<tr>
<td>Intermediate</td>
<td>Material which is difficult to excavate by hand even with the aid of a crow bar and requires the assistance of pneumatic tools for economical removal.</td>
</tr>
<tr>
<td>Rock</td>
<td>Material which cannot be economically fragmented and loosened for removal by hand implements and pneumatic tools except by drilling and blasting or the use of rock breaking equipment.</td>
</tr>
</tbody>
</table>

**Table 7: Classification of materials in terms of consistency and shear strength (Soderlund & Schutte, 1994)**

<table>
<thead>
<tr>
<th>Materials Classification</th>
<th>Consistency (as defined in table 6)</th>
<th>Typical number of blows that a DCP # requires to penetrate 100 mm of material +</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Granular Soil</td>
<td>Cohesive Soil</td>
</tr>
<tr>
<td>Soft, Class 1</td>
<td>Very Loose/Loose</td>
<td>Very Soft/Soft</td>
</tr>
<tr>
<td>Soft, Class 2</td>
<td>Loose/Medium Dense</td>
<td>Soft/Stiff</td>
</tr>
<tr>
<td>Soft, Class 3</td>
<td>Dense</td>
<td>Stiff/Very Stiff</td>
</tr>
<tr>
<td>Intermediate</td>
<td>Very Dense</td>
<td>Very Stiff</td>
</tr>
<tr>
<td>Rock</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

+ Only applicable to materials comprising not more than 10% gravel (particles having dimensions 2.5 mm) of size less than 10 mm and materials containing no isolated small boulders.

# Refer to Appendix A for description of DCP and its common usage in South Africa.

### 1.4.4.3 Service trenches

Extracts from Soderlund and Schutte's pre SABS 1200 backfilling specification required that the initial refill material up to 0.3 m above the barrels of pipes shall consist of selected material, free of stones with a largest dimension in excess of 20 mm, well compacted by the use of approved hand tools under the direction of the pipe layer. The refilling of trenches above the initial refilling layer shall be
carried out in layers not exceeding 150 mm compacted thickness. All refill material shall be readily compactible material, free from roots and other vegetable matter, building rubble, etc. Refilling under existing, or future, road surfaces shall be compacted to 93% Modified AASHTO maximum density and other refilling to 87% Modified AASHTO maximum density. Where practicable, approved mechanical compacting equipment shall be used. Refilled trenches shall be finished off approximately 50 mm proud of original ground surfaces.

This specification placed the onus of prevention of settlement on the contractor viz., during the whole period that the works are in his hands, including the maintenance period, and as often as necessary, the contractor shall make good promptly and at his own cost all surface settlements caused by his excavations. He shall be held liable for any accidents or damage arising from such settlements.

The SABS 1200 series set a minimum compaction requirement of 90% Modified AASHTO density at optimum moisture content. This level of compaction is in excess of what is required to contain trench settlements to within acceptable limits (87 - 88%) in untrafficked areas. It can only be achieved by using mechanical compaction equipment and not by means of hand methods with any degree of consistency.

A test to provide compaction characteristics of soil was first introduced by Proctor in the USA in 1933 as a means of controlling the degree of compaction during construction. Proctor’s test represented in the laboratory the state of compaction which could be reasonably achieved in the field. However, with the subsequent introduction of heavier earth moving and compaction equipment, higher densities became obtainable in practice. A laboratory test using increased energy of compaction was then introduced to reproduce higher compacted densities viz. Modified AASHTO test. (It should be noted that the current test equipment (mould size and hammer mass), drop height of the hammer and test procedures (number of layers and number of blows per layers) vary from country to country.)
Table 8: Consistency of materials (SABS 0161)

<table>
<thead>
<tr>
<th>Consistency</th>
<th>Description</th>
<th>Consistency</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very loose</td>
<td>Crumbles very easily when scraped with a geological pick.</td>
<td>Very soft</td>
<td>Geological pick head can easily be pushed in as far as the shaft of the handle.</td>
</tr>
<tr>
<td>Loose</td>
<td>Small resistance to penetration by sharp end of a geological pick.</td>
<td>Soft</td>
<td>Easily dented by thumb; sharp end of a geological pick can be pushed in 30-40 mm; can be moulded by fingers with some pressure.</td>
</tr>
<tr>
<td>Medium dense</td>
<td>Considerable resistance to penetration by sharp end of a geological pick.</td>
<td>Firm</td>
<td>Indented by thumb with effort; sharp end of geological pick can be pushed in up to 10 mm; very difficult to mould with fingers; can just be penetrated with an ordinary hand spade.</td>
</tr>
<tr>
<td>Dense</td>
<td>Very high resistance to penetration by the sharp end of geological pick; requires many blows for excavation.</td>
<td>Stiff</td>
<td>Can be indented by thumb-nail; slight indentation produced by pushing geological pick point into soil; cannot be moulded by fingers.</td>
</tr>
<tr>
<td>Very dense</td>
<td>High resistance to repeated blows of a geological pick.</td>
<td>Very stiff</td>
<td>Indented by thumb-nail with difficulty; slight indentation produced by blow of a geological pick point.</td>
</tr>
</tbody>
</table>
Table 9: Typical rates of production for different classes of materials in trench excavations. (Watermeyer and Band, 1994)

<table>
<thead>
<tr>
<th>Excavation Type</th>
<th>Typical Daily Production For Depth Range (M$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 - 1.0</td>
</tr>
<tr>
<td>Soft, Class 1</td>
<td>3.5</td>
</tr>
<tr>
<td>Soft, Class 2</td>
<td>2.8</td>
</tr>
<tr>
<td>Soft, Class 3</td>
<td>1.7</td>
</tr>
</tbody>
</table>

The increase in the dry density of soil produced by compaction depends mainly on the moisture content of the soil and on the amount of compaction applied. Table 10 compares the differences between the Proctor and Modified AASHTO compaction tests. It is immediately evident from Table 10 that heavier plant requires significantly more moisture to reach maximum dry density.

Table 10: Comparison of results of the standard Proctor and Modified AASHTO Compaction Tests

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Average results of BS Compaction Test</th>
<th>Average effect on modified AASHTO test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum dry density (kg/m$^3$)</td>
<td>Optimum moisture content (%)</td>
</tr>
<tr>
<td>Heavy clay</td>
<td>1555</td>
<td>28</td>
</tr>
<tr>
<td>Silty clay</td>
<td>1670</td>
<td>21</td>
</tr>
<tr>
<td>Sandy clay</td>
<td>1840</td>
<td>14</td>
</tr>
<tr>
<td>Sand</td>
<td>1940</td>
<td>11</td>
</tr>
<tr>
<td>Gravel-sand clay</td>
<td>2070</td>
<td>9</td>
</tr>
</tbody>
</table>

Accordingly, density requirements where light equipment or hand stamping is used should rather be measured in terms of Proctor densities and a value of 90% Proctor density should suffice for untrafficked areas. This is achievable by means of hand stamping.

DCPs can be readily used to control compaction in untrafficked trenches. Material with a medium dense / stiff consistency (refer to Table 7) is unlikely to settle. A value of not more than five blows / 100 mm of material can be used to specify the compaction requirements. Horak (1993) produced a specification for trench reinstatements across trafficked areas using DCPs and Rapid Compaction Control Devices (a spring loaded steel rod with a 32 degree cone shaped point complete with trigger mechanism). Horak’s specification is reproduced in Table 11. It is based on CBR requirements of the various layers (refer to Appendix A).
1.4.4.4 **Pipe bedding material**

The material placed around a pipe (bedding) significantly influences the engineering performance of a pipe i.e. its load capacity and its deflection for a given load. The performance of flexible pipelines is particularly sensitive to the bedding material which is used. As the value of the soil modulus is related to both the soil type and the degree of compaction. Conventional specifications usually set grading and Atterburg limits for the material and require that this layer be compacted to a density of not less than 90% modified AASHTO without giving a thought as to how this density is to be measured.

A more pragmatic solution is to perform the compaction fraction test described below to determine if the material can be readily compacted. An acceptable bedding material will be one which can be readily compacted with minimal compactive effort.

**Compaction fraction tests**

**Apparatus**

A 250 mm long open-ended cylinder with a bore of diameter approximately 150 mm, a metal rammer 40 mm in diameter and weighing 1 kg, and a measuring rule.

**Procedure**

a) Obtain a representative sample more than sufficient to fill the cylinder.

b) Place the cylinder on a firm, flat surface and put the sample into the cylinder, loosely and without tamping, until it is over-filled.

c) Strike off the top surface of the material level with the top of the cylinder and remove the surplus material.

d) Lift the cylinder clear of its contents and place on a clean area of the work surface.

e) Place about one quarter of the material into the cylinder and tamp until no further compaction is obtained.

f) Repeat for the remaining quarters, ensuring the final surface is as level as possible. Measure down from the top of the cylinder to the top of the compacted material and express this measurement as a fraction of 250 mm to give the compaction fraction (CF).

**Suitability of material**

Material with a CF greater than 0.30 (i.e. the distance from the top of the cylinder to the top of trenches, the compacted material exceeds 100 mm) should not be used as selected bedding cradle material.
Table 11: Trench reinstatement compaction specification (roads and footways) (Horak 1993)

<table>
<thead>
<tr>
<th>Road (footways) layer</th>
<th>Material description</th>
<th>Thickness [road category]</th>
<th>Compaction standard</th>
<th>DCP penetration [mm/blow]</th>
<th>RCCD penetration [mm/3 blows]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surfacing</td>
<td>BS and BS cold mix or hot mix</td>
<td>50 mm [all roads]</td>
<td>95% Marshall Less than 2 [only as a guide]</td>
<td>Less than 9 [only as a guide]</td>
<td></td>
</tr>
<tr>
<td>Surfacing base</td>
<td>BC and BS cold mix or hot premix</td>
<td>50 mm [residential] 150 mm [arterials]</td>
<td>05% Marshall Less than 2 [only as a guide]</td>
<td>Less than 9 [only as a guide]</td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>G3, G4 crushed stone or natural gravel or C3, C4 cementitious gravel or BT emulsion treated gravel</td>
<td>150 mm [all roads]</td>
<td>98% MAASHTO Less than 9</td>
<td>Less than 45</td>
<td></td>
</tr>
<tr>
<td>Subbase [footway base]</td>
<td>G4, G5, G6 natural gravel or C3, C4 cementitious gravel or BT emulsion treated gravel</td>
<td>150 mm [all roads]</td>
<td>98% MAASHTO Less than 4</td>
<td>Less than 18</td>
<td></td>
</tr>
<tr>
<td>Subgrade [footways and roads]</td>
<td>G5, G6, G6, G8 natural gravel</td>
<td>Anything below 600 mm in lifts of 150 mm</td>
<td>90% MAASHTO Less than 19</td>
<td>Less than 95</td>
<td></td>
</tr>
<tr>
<td>Selected subgrade [footway subbase]</td>
<td>G5, G6, G7 natural gravel or cementitious or emulsion modification</td>
<td>150 mm [all roads]</td>
<td>93% MAASHTO Less than 14</td>
<td>Less than 75</td>
<td></td>
</tr>
</tbody>
</table>

* Refer to TRH14 for material descriptions

1.4.4.5 Construction materials

Quality may be regarded as conformance to stated requirements (specifications) rather than fitness for a given purpose. It is achieved by executing a contract to stated requirements. Small scale entrepreneurs have particular problems in achieving quality, depending upon how quality is measured and defined. Current practice is to define quality in terms of certain accepted criteria and to measure
acceptance in terms of prescribed test methods and procedures. These are usually set out in national specifications such as those published by the South African Bureau of Standards, or test methods which have, to a large extent, been formulated or drafted with the approval of industry and industry-related research and development organisations.

It may be argued that these standards have been drafted to suit the well established industry and are framed around plant-based methods of manufacture and medium to large scale enterprises which have a reasonable degree of technical competency and testing resources. In addition, the test methods and procedures for quality assurance are generally written for a scale of operation where sufficient quantities for statistical purposes are manufactured, and the cost of testing by external authorities (or that associated with the establishment of in house laboratories) can be written off against the volume of the article which is manufactured. Failure by a small scale manufacturer to comply with one of the requirements of these specifications, albeit a relatively minor lack of compliance, means that compliance with a national standard cannot be claimed. Thus, in effect, many of the current specifications present a barrier to entry to small scale entrepreneurs and exclude their participation in particular markets.

The National Home Builder’s Registration Council in drafting their Standards and Guidelines (1995), a document which was prepared to manage mortgage lenders’ risk of defects arising in housing to acceptable limits, departed from the conventional approach to drafting standards and kept references to South African national standards and codes of practice to an absolute minimum. The Standards and Guidelines rather listed salient and relevant requirements which needed to be satisfied. Two examples of the manner in which masonry and sands for mortar are described in their updated, unpublished second edition are reproduced below.

1.4.4.6 Sand for mortar

Sand for use in mortar shall either comply with the relevant requirements of SABS 1090 or all of the following:-

- contain no organic material (material produced by animal or plant activities).
- does not contain any particles which are retained on a sieve of nominal size 5mm.
- have a clay content such that a “worm” 3mm in diameter cannot be rolled in the palm of the hand, by adding a few drops of water to material obtained from the sieving of a sample of dry sand through a nylon stocking.
- when 2.5kg of common cement is mixed to 12.5kg of air-dry sand, the mixture does not require more than 3.0 litres of water to be added to reach a consistency suitable for plastering and the laying of masonry.
- when mixed with common cement in accordance with the mix proportions, has adequate workability.

The standards and guidelines offer the following guidelines in this regard:

- Mortars are best when coarse and medium sand fractions are predominant. These sizes can be viewed through a transparent plastic ruler using a hand lens. (Place graduals on ruler over sand):-
  
  **Very coarse** 5-2.5mm
Coarse sand 2.5-1.0mm
Medium sand 1.0-0.25mm
Fine sand 0.25-0.125mm

The visual examination should reveal a high proportion of coarse and medium sand fractions but also some very coarse sand.

If the visual measurement of sand indicates that it is too coarse or too fine, a complimentary sand should be sought and blended with the original sand to improve performance.

- The clay content of a sand can be assessed by rolling the portion of the material which passes through a 0.075 mm sieve into a worm. 0.075 mm sieves are normally only found in a laboratory. For a field test, place a few handfuls of sand in the foot of a nylon stocking with its end tied. Shake the sand and collect the dust in a container.

The Standards and Guidelines offer the following advice on assessing and improving the workability of the mortar:

- Place a small quantity of the mix (at plastering / masonry laying consistency) on a non-absorbent surface and form a flattened heap about 100 mm high and 200 mm in diameter. Place a plasterer’s trowel face down on top of the heap and push the trowel downwards.

- A mix with adequate workability is one which permits the mix to squeeze out from under the trowel and allows the trowel to be pushed to within a few millimetres of the underlying surface. An unworkable mix will “lock up” once the trowel has moved a few millimetres and prevents further downward movement of the trowel.

- The workability of a mix may be improved by adding hydrated bedding lime to the mix (limes used in South Africa do not have cementing properties. They cannot be used to replace cement but are used in addition to common cement). Alternatively, a masonry cement (a blend of Portland cement, ground limestone or hydrated lime and/or an air entrainment agent) may be used in place of a common cement to improve the cohesiveness and plasticity of the mix.
1.4.4.7 Masonry units

Masonry units shall:

- have an average and minimum individual compressive system of not less than that contained in Table 12.
- have dimensions such that the units can be built into walls within prescribed joint tolerances, to the required bond pattern and corners can be constructed in accordance with certain prescribed requirements (elsewhere described).
- not exhibit excessive surface pop-outs, should units contain slag, clinker or burnt clay aggregate.

Table 12: Minimum compressive strengths of masonry units

<table>
<thead>
<tr>
<th>Description</th>
<th>Hollow Units</th>
<th>Solid Units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average (MPa) Individual (MPa)</td>
<td>Average (MPa) Individual (MPa)</td>
</tr>
<tr>
<td>Single storey construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• on-site manufacture</td>
<td>3.0</td>
<td>2.4</td>
</tr>
<tr>
<td>• off-site manufacture</td>
<td>3.0</td>
<td>2.4</td>
</tr>
<tr>
<td>Double storey construction</td>
<td>7.0</td>
<td>5.6</td>
</tr>
<tr>
<td>Cladding and internal walls in concrete framed housing units</td>
<td>3.0</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Notes
1. The average compressive strength shall be determined on a minimum of five samples based on the gross surface area.
2. On site manufacture is where units do not require to be transported more than 25m to the place where they are built into walls.

- Masonry units shall be of a quality such that, when delivered to the point of use, they are intact and have no corner chips having horizontal and vertical dimensions exceeding 15mm.
- Face shells and webs of hollow units shall not be less than 25mm thick.
- Calcium silicate units shall either have a demonstrated drying shrinkage of not more than 0.045% or not be built into walls within 10 days from the date of manufacture.
- Concrete masonry units shall either have a demonstrated drying shrinkage of not more than 0.06% or not be built into walls within 21 days from the date of manufacture.
- Burnt clay masonry units shall in general have an irreversible moisture expansion of not more than 0.20% and, in faced applications, a demonstrated satisfactory performance with respect to durability unless it can be reasonable demonstrated by other means that the units are fit for the specified purpose.

The commentary to their specification, inter alia, states that manufacturers should manufacture units having a target strength in excess of the average to ensure that the average and minimum strength requirements are met. Experience has shown that in the manufacture of concrete masonry units, the target strength is a function of the degree of quality control that is exercised. The target strengths set out in Table 13 are recommended for the manufacture of concrete masonry units.
to ensure that there is a 95% certainty that the average strengths will be achieved.

Table 13: Target compressive strengths for manufacturing purposes

<table>
<thead>
<tr>
<th>Specified average compressive strength (MPa)</th>
<th>Target compressive strength (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level of manufacturing</td>
</tr>
<tr>
<td></td>
<td>Poor</td>
</tr>
<tr>
<td>3.0</td>
<td>5.0</td>
</tr>
<tr>
<td>4.0</td>
<td>6.6</td>
</tr>
<tr>
<td>5.0</td>
<td>8.3</td>
</tr>
<tr>
<td>7.0</td>
<td>12.0</td>
</tr>
<tr>
<td>10.0</td>
<td>17.5</td>
</tr>
</tbody>
</table>

The above mentioned masonry specification enables on site manufacture of concrete masonry units to be performed in a cost effective manner. (Higher compressive strengths favour plant-based manufacturers with relatively high capital investments as such manufacturers can produce adequate strength blocks with low cement : aggregate ratios. Simple equipment requires higher cement : aggregate ratios to achieve similar strengths.)

The NHBRC’s requirements facilitates the entry of small scale / local manufacturers / producers into the market without sacrificing quality as the product which is incorporated into a housing unit is fit for its intended purpose. Should ancillary roadworks materials be described in a similar manner, local / small scale manufacturers will be able to access the market.

1.4.5 Targeted Procurement

1.4.5.1 Overview

Targeted or affirmative procurement is a form of procurement which has been developed in South Africa by a task team overseen by the Procurement Forum (an initiative of the Ministry of Finance and Ministry of Public Works) which was tasked with effecting public sector procurement reform in South Africa.

The Procurement Forum’s Affirmative Procurement Policy (APP) makes provision for the setting of the socio-economic targets and has developed delivery systems designed to facilitate the participation of these targeted groups in a manner which is:

- definable;
- quantifiable;
- measurable;
- auditable; and
• verifiable

This is achieved without compromising the principles of fairness, competition, cost efficiency and inclusion, through a combination of:

• the classification of contracts;
• the use of human resource specifications; and
• the use of development objectives/price mechanisms (i.e., points scoring tender adjudication systems in terms of which tenderers are awarded points for, in the first instance, their financial offers and, in the second instance, the extent to which their offers exceed socio-economic objectives, or for their current enterprise status).

1.4.5.2 Human resource specifications

Human resource specifications govern the manner in which prime or main contractors structure and marshall their resources in order to meet their contractual obligations. They define and set goals for targeted small, medium and micro enterprise participation, or the engagement of targeted labour / local resources, in the performance of contracts in such a manner that they can be quantified, measured, verified and audited. Human resource specifications require prime contractors to “unpack” their contracts into smaller contracts in order to procure the services of targeted small, medium and micro enterprises and to administer such contracts. Alternatively, they require prime contractors to structure their resources in the performance of their contracts in order to provide work opportunities to targeted labour or to measure the increase in the number of employment opportunities generated per unit of expenditure or to engage in joint ventures with targeted groups.

The Procurement Task Team has released through the Procurement Forum the following human resource specifications which may be used in engineering and construction works contracts:

Affirmative Procurement Policy (APP1): The Targeting of Affirmable Business Enterprises

APP2: Structured Joint Ventures (General)

APP3: Structured Joint Ventures (Targeted)

APP4: Targeting of Local Resources

APP5: Engagement of Targeted Labour

Typically, these specifications provide for:

• the setting of targets (contractual goals) to secure the participation of the targeted group; and
• the measurement of key participation indicators to be used in the evaluation of tenders and the audit of participation compliance during the execution of the contract.

Each specification:

• establishes the general principles for the participation of the targeted group
• provides information on the contractual goals and how these goals may be achieved
• specifies requirements for contractors and how they may fulfil these requirements
• defines and interprets the words and expressions.

1.4.5.3 Contract classification

General
The Procurement Forum recognised that a classification of contracts is required to enable contracts to be:
• packaged (unbundled) in a manner which facilitates targeted small, medium and micro enterprise participation; or
• structured in a manner to permit emerging/historically disadvantaged contractors to participate, develop and be integrated into the mainstream of the economy.

The Procurement Forum in the 10 Point (Interim Strategies) Plan (1995) developed such a classification by classifying contracts in the first instance on the basis of risk to the parties and the scale of the resources required to execute a contract (class) and in the second instance on who the contracting parties are (type).

Class of contract
Contracts may be classified on the basis of risk to the parties and the scale of the resources required to execute the contract as follows:
• international
• major
• micro
• minor

The 10 Point Plan defines a minor contracts in terms of size, complexity, novelty/innovation, intensity (speed of design and construction), physical location, likelihood of variations in scope, quality of completed works and responsibilities viz., a contract in which:
• the risks for both contracting parties are adjudged to be small;
• the period for completion of the contract does not normally exceed six months and certainly not 12 months;
• the contract value is usually less than R1 million, but in no circumstances exceeds R2 million;
• the works are of a straightforward nature and the possibility of significant variation from the work envisaged is adjudged to be relatively low;
• the site establishment requirements are adjudged not to be onerous;
• the contractor has no responsibility for the design of the permanent works other than for possible minor items;

• the design of the works, save for design work for which the contractor is made responsible, is complete in all essentials before tenders are invited;

• the contractor’s responsibility for the appointment of nominated/selected subcontractors is limited;

• the contractor is not required to undertake work of a specialist nature.

Major contracts have more onerous requirements than those for minor contracts. International contracts are those for which the necessary resources are adjudged to be beyond the capacity / capabilities of most large South African companies. Alternatively, they are contracts which are likely to attract foreign competition. Micro contracts, on the other hand, are contracts which have less onerous requirements than minor contracts.

**Type of contract**

Contracts may also be classified in terms of who the contracting parties are as follows:

• prime

• structured joint ventures

• community/development

This classification of contracts is based on the premise that construction is the synthesis of four functional activities, viz., construction management; materials management; materials supply and physical work (labour, plant and equipment).

A prime contract is accordingly a contract in which:

• the contractor has the resources to perform all these functional activities unassisted by other contracting parties, separately appointed by the employer; or

• the contractor has the resources to perform some of the functional activities and is able to marshall resources for the remainder.

A structured joint venture contract is a contract in which:

• the senior joint venture contractor is a prime contractor and the junior partner, who may lack skills in certain functional areas, is able, through the joint venture formation to participate and develop in these areas; or

• both joint venture partners may be prime contractors with one of the parties having limited resources and capacity.

A development contract is a contract in which:

• the employer appoints third parties to provide certain resources which community / emerging contractors may lack

• the contractor who performs the physical work, or aspects thereof, has a contract with the employer.
There is no contract between the third party support and the contractor.

The contractor supported by a third party management support may be collectively regarded as the “prime contractor”.

A community contract is a labour-only contract which is conceived and structured in a manner which secures the participation of groups or teams of residents within specific communities in projects.

(A development contract is identical to Level 1 to Level 3 contracts in terms of Soweto’s Contractor Development Programme, Watermeyer, 1992; prime minor contracts are the same as Levels 4 and 5 contracts.)

**Combining contract type and class**

The type and class of prime contracts may be combined as follows:

- prime (international);
- prime (major)
- prime (minor)
- prime (micro)

Typically prime (micro) contracts are aimed at providing work opportunities for small and micro enterprises; operating as prime contractors; prime (minor) contracts for small and medium enterprises; and prime (major) contracts for medium and large enterprises.

**Implications of the contract classification**

The system of contract classification can be used as a tool for redressing the skewed nature of the economy. Development contracts can be used to facilitate the successive introduction of labour, transport, materials, plant and finance into community-based/developing enterprises in structured programmes. Certainly, the associated contractual arrangements will permit such enterprises, through the execution of contracts, to establish themselves and to acquire the necessary skills required in respect of materials supply, materials management and construction management.

Work opportunities can be created for those exiting such programmes to ensure the sustainability of the enterprises that have been developed. This can be achieved by making prime contracts (micro) and (minor) accessible to those who have been developed through development contracts and by requiring prime contractors operating in the prime (major) class of contract to make use of the services of emerging contractors.

The contractor classification system can also be effectively utilised to create work opportunities for targeted groups and individuals without guaranteeing them work.

The classification of contracts on the basis of risk, permits the level of performance bonds to be varied without exposing the client body to unacceptable risk, viz.:

- prime (major and international) 10%
• prime (minor) - contract value < R1.0m 2.5%
• contract value between R1.0m and R2.0m 5%
• prime (micro) nil
• structured joint venture 10%
• development nil

It should be noted in development contracts the third party management support is frequently required to carry professional indemnity insurance.

**Development objective/Price mechanisms**

**General**

A development objective/price mechanism is a point scoring system in terms of which tenderers are awarded, in the first instance, points for their financial offers and in the second instance, for the extent to which their offers exceed socio-economic objectives, or their current enterprise status.

Development objective points are awarded to tenderers who exceed minimum goals set in terms of human resource specifications in order to encourage tenderers to make the optimum economic use of one of more of the following in the performance of the contract:

• local labour
• targeted labour
• local resources
• Affirmable Business Enterprises (ABEs: Black owned small, medium and micro enterprises)
• targeted enterprises

In this manner, the premium payable for incorporating socio-economic objectives into projects is minimised, as tenderers compete both on the basis of price and of meeting socio-economic objectives. Market forces dictate the degree to which contractors can meet socio-economic objectives in the most cost effective manner.

Development objective points can also be awarded to enterprises on the basis of their status as an ABE or the amount of Women Equity Ownership within an enterprise. The use of the development objective/price mechanism in this instance is a form of price preference. Although the target group receives a price preference, they nevertheless have to submit competitive tenders to be awarded contracts.

The successful tender is the one which is awarded the most points, subject always to technical factors, previous contractual performance/recommendations, financial references, unit rates and prices, alternative offers, qualifications etc., being acceptable. This system of tender adjudication replaces the practice of awarding the tender to the lowest priced offer, as it permits human resource / socio-economic objective offers to be considered together with the financial offer.

The use of a development objective / price mechanism:
• enables tenderers to use their skill, knowledge and creativity in arriving at a favourable mix between economic and development objectives.

• penalises those persons who fall outside the targeted groups, or who offer to meet certain socio-economic objectives to only a limited degree, but does not preclude them from tendering (i.e. engaging in economic activity) in a meaningful manner.

• prevents those who fall within a targeted group from presenting grossly non-competitive tender prices, as the reward for compliance with socio-economic objectives will be outweighed by the loss of points incurred through non-competitive tender prices.

**Points awarded for the financial offer**

Points awarded in respect of the financial offer are calculated as follows:

\[ N_p = Z \left(1 - \frac{(P - P_m)}{P_m}\right) \]

where:

- \( N_p \) = the number of tender adjudication points awarded on the basis of price
- \( P_m \) = the price of the lowest responsive tender adjusted to a common base, if applicable.
- \( P \) = the price of the responsive tender under consideration adjusted to a common base, if applicable.
- \( Z \) = a number, usually 90
Points awarded for development objectives

The maximum number of development objective points awarded to a tenderer should in general not exceed 10.

Points awarded in terms of an enterprises status are fixed in respect of ABEs and vary, depending on the ownership percentages, in respect of Women Equity Ownership.

Points awarded in respect of increased human resource goals in respect of specifications APP1, APP2, APP3, APP4 and APP5 are awarded in terms of the following formula:

\[ N_c = \frac{X (D - D_s)}{Y - D_s} \]

where

- \( N_c \) = number of tender adjudication points awarded.
- \( D \) = the tendered goal percentage in the tender under consideration.
- \( D_s \) = the specified minimum goal percentage
- \( X \) = maximum number of adjudication points assigned for the socio-economic aspect of the tender (usually 10 points).
- \( Y \) = goal percentage above which no further tender adjudication points are awarded.

Tenderers, in terms of the above formula, obtain the maximum number of points (\( N_c \)) should they tender a goal of \( Y\% \) and have no advantage over their competitors, should they tender a value in excess of \( Y\% \).

Standard delivery options

The standard delivery options for various targeted groups which have been provided for are as set out in Table 14. The framework can be used to create work opportunities for targeted groups and individuals.
<table>
<thead>
<tr>
<th>Contract</th>
<th>Targeting Options</th>
<th>Human resource specifications</th>
</tr>
</thead>
</table>
| Prime    | • SMMEs owned and controlled by previously disadvantaged individuals  
|          | • local resources (i.e. local enterprises, manufacturers and labour).  
|          | • increase in number of person hours employment generated per unit of expenditure  
|          | • local labour  
| Prime    | • small and medium enterprises particularly those having women equity ownership or which are owned and controlled by previously disadvantaged individuals.  
| Prime    | • small and micro enterprises particularly those having women equity ownership or which are owned and controlled by previously disadvantaged individuals.  
| Structured Joint Venture | • emerging enterprises owned and controlled by previously disadvantaged individuals  
|          | • specific emerging enterprises.  
| Development | • emerging enterprises or aspirant entrepreneurs who do not have the capabilities or resources to contract as prime contractors.  
| Community | • groups or teams of residents within specific communities who, with support and training, can undertake labour only contracts and so participate in projects. |

Contract classification is a form of targeting and can as such be used to secure in an indirect manner work for contractors who are operating within certain sectors within the construction industry. For example, development contracts are aimed at emerging contractors who carry no significant overhead costs and do not have in their employ persons with the necessary management skills to perform all the materials procurement and construction management functions required in prime contracts. Established contractors who possess these resources, carry higher associated overhead costs and contracting capacities and as such are not
attracted to this type of contract. Furthermore they normally cannot match the tendered prices of the targeted group.

**Unbundling strategies (breakout procurement)**

Small, medium and micro enterprises can participate in public sector procurement in one of two ways. They can either contract directly with an organ of state or participate as a subcontractor, supplier or service provider to a prime contractor in the delivery chain.

The breaking down of tenders into smaller components is not always justifiable owing to the division of responsibilities, interdependence of activities, programming, duplication of establishment charges and under utilisation of resources. Furthermore, the administration of such contracts by organs of state and their agents is more complex and costly than is that of fewer larger ones.

The targeted procurement strategies enable contracts to be unbundled in a number of ways, viz.:

- by procuring works in the smallest practicable quantities (prime (minor and micro)).
- by obligating prime contractors to engage targeted businesses in the performance of their contracts (prime (international and major) with APP1 and APP4 specifications).
- by requiring joint venture formation between established businesses and targeted emerging business enterprises (structured joint venture with APP2 and APP3 specifications).
- by providing third party management support to enterprises which are not capable of operating as prime contractors (development contracts).

The options which make use of human resource specifications require prime contractors to “unpack” their contracts into smaller contracts and to procure the services of small, medium and micro enterprises to perform such contracts and to administer them.

The unbundling strategies, with the exception of the prime (minor and micro) option, afford the full spectrum of small, medium and micro contractors i.e. those operating as labour-only contractors to those operating as prime contractors, opportunities of participation. It is therefore not a prerequisite for a contractor to have the necessary tools and equipment to participate in contracts as the prime (major) contractors, established senior joint venture partners as the third party management support may provide or make available such tools and equipment in order to secure their participation.

1.4.5.4 **Encouraging contractors to make more use of targeted labour in excavation activities**

In order to meet goals for the engagement of targeted labour or to tender increased goals, contractors may have to undertake some or all soft excavations by the use of hand labour. In order to minimise their risk exposure to performing such activities, there needs to be:

- a labour policy in place which sets out the conditions of employment for temporary workers (i.e. project specific workers)
• a mechanism in terms of which contractors can define the portion of the excavation works which will be excavated by hand methods.

If this is not done, contractors will not be able to increase job opportunities in earthworks activities as they would be exposed to unacceptable risks. The above mentioned employment policy and mechanism should accordingly be clearly set out in the tender documents and form an integral part of the contract.

A suitable mechanism to enable contractors to define portions of excavation work which may be excavated by means of hand methods, is to permit contractors during the tender stage to nominate the quantity of materials which they wish to execute using hand methods. The approach outlined below is suggested.

The initial classification of material to be excavated should be in accordance with the relevant provisions of standard earthworks specifications such as SABS 1200 D and 1200 DA. However, soft excavation to be undertaken by hand labour, using hand tools, can be further broken down by the introduction of an additional class of material, viz., soft excavation Class A, in accordance with the provisions of the project specification as tabulated in Table 15.

Table 15: Criteria for classifying materials as soft class A excavation

<table>
<thead>
<tr>
<th>Material type</th>
<th>Granular materials</th>
<th>Cohesive materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic cone penetrometer - minimum number of blows required to penetrate 100 mm</td>
<td>7 - 15</td>
<td>6 - 8</td>
</tr>
<tr>
<td>Consistency</td>
<td>Dense - high resistance to penetration by the point of a geological pick; several blows required for removal of material.</td>
<td></td>
</tr>
</tbody>
</table>

*Soft excavation Class A is material which, using a pick or equivalent hand swing tool, can only be excavated with difficulty.*

The total estimated quantity of excavation, as classified in terms of a standard earthworks specification, should be indicated in the Schedules. The tenderer should be permitted to sub divide this quantity into two components, viz., the quantity of material to be excavated by the use of powered, mechanical equipment and the quantity to be excavated by hand labour using hand tools.

One third (\(\frac{1}{3}\)) of every quantity of excavation to be undertaken by hand labour should be entered against the appropriate extra-over items provided in the Schedules, but left blank, for soft excavation Class A. This will ensure that material which can be picked with difficulty is catered for and the transition from hand excavation to machine excavation is graded.

Should the tenderer fail to indicate a quantity of excavation to be undertaken by hand labour, notwithstanding that he would find it necessary to utilise hand labour, it will be assumed that all excavation, whether undertaken by machine, or by hand labour, is to be paid for at the rates tendered for machine excavation.

The contractor should be required to undertake at least the quantities of excavation by hand labour which he tendered, unless the total quantity of excavation proves to be less than scheduled, in which case the minimum quantity
to be undertaken by hand labour will be reduced pro-rata by the employer’s representative. This procedure will also provide a basis for reducing targeted labour goals should such adjustments be necessary.

Should the total quantity of excavation prove to be greater than that scheduled, the contractor may choose the method of excavation for the excess quantity, unless the rates for excavation by machine would result in lower costs than hand excavation, in which case the employer’s representative will have the right to instruct the contractor to undertake the excavation by machine.

### 1.4.5.5 Implementing targeted procurement in South Africa

The National Department of Public Works first made use of a human resource specification during the early part of 1996 on the Malmesbury Prison and Housing Project, on develop and build contracts having a contract value of US$ 41m. The Affirmable Business Enterprise (ABE) participation which was achieved, as measured in terms of the APP1 specification, amounted to 38.8% (Gounden 1997).

Since August 1996, the department has applied an Affirmative Procurement Policy (APP) to all its construction projects. Gounden (1997) writes; “for the period August 1996 to July 1997, 2,206 building and civil contracts totalling US$ 190 million were let utilising the Affirmative Procurement Policy specifications. 38.4% (US$ 73m) of the total financial value of these contracts went to ABEs either as prime contractors on the smaller projects or as joint venture partners, subcontractors and service providers on the larger projects”.

When the programme commenced in August 1996, some commentators predicted that a financial premium of the order of 10 - 15% per project would be incurred by the implementations of the APP specifications. Table 16 indicates the actual premiums paid for the period under review (August 1996 - July 1997). As can be seen from Table 16, the overall financial premium that has been paid to date is 1.23%. Measured against the benefits that will accrue to the country by broadening the construction base, this premium can be justified.

Gounden (1997) has also gathered data on the increase of ABE participation in the National Public Works Department’s construction projects over a period of three years (see Table 17). He attributes the significant increase in ABE participation largely to the implementation of the Affirmative Procurement Policy which commenced in August 1996.
Table 16: Analysis of ABE participation in 2206 construction contracts (Gounden 1997)

<table>
<thead>
<tr>
<th>Range of contract (US$)</th>
<th>No of ABE contracts awarded</th>
<th>ABE contract total (US$)</th>
<th>Sum of lowest bids (US$)</th>
<th>Difference between ABE awards and lowest bids (US $)</th>
<th>% premium</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 9800</td>
<td>561</td>
<td>870,000</td>
<td>859,000</td>
<td>11,000</td>
<td>1.28</td>
</tr>
<tr>
<td>9800 - 22000</td>
<td>92</td>
<td>1,353,000</td>
<td>1,337,000</td>
<td>16,000</td>
<td>1.20</td>
</tr>
<tr>
<td>22000 - 110,000</td>
<td>75</td>
<td>2,845,000</td>
<td>2,696,000</td>
<td>149,000</td>
<td>5.53</td>
</tr>
<tr>
<td>110,000 - 430,000</td>
<td>13</td>
<td>2,335,000</td>
<td>2,176,000</td>
<td>159,000</td>
<td>7.31</td>
</tr>
<tr>
<td>+ 430,000</td>
<td>18</td>
<td>48,592,000</td>
<td>48,249,000</td>
<td>343,000</td>
<td>0.71</td>
</tr>
<tr>
<td>Total</td>
<td>759</td>
<td>55,995,999</td>
<td>55,317,000</td>
<td>678,000</td>
<td>1.23</td>
</tr>
</tbody>
</table>

Table 17: Participation of ABEs in National Department Public Works Construction projects 1994-1997 (Gounden 1997)

<table>
<thead>
<tr>
<th>Financial Year</th>
<th>Total Number of Contracts with ABE participation (%)</th>
<th>Total Financial Value of Contracts with ABE participation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994/1995</td>
<td>7.6</td>
<td>16.5</td>
</tr>
<tr>
<td>1995/1996</td>
<td>33.1</td>
<td>22.0</td>
</tr>
<tr>
<td>1996/1997*</td>
<td>48.3</td>
<td>37.3</td>
</tr>
</tbody>
</table>

*: This significant increase in ABE participation in Public Works construction projects during this period could largely be attributed to the implementation of the Affirmative Procurement Policy which commenced in August 1996.

Watermeyer (1997) reports that the Southern Metropolitan Local Council (SMLC) of the Greater Johannesburg Metropolitan Council has recently implemented a number of projects using the APP5 specification and development objective price mechanisms. Targeted labour has been defined as South African citizens residing within the geographical area over which the SMLC has jurisdiction and who earn less than R9-00 per hour. The targeted labour goals (Rand value of wages and allowances for which the contractor contracts to engage targeted labour in the performance of the contract, expressed as a percentage of the net tender value) of the successful tenderer and the cost premium associated with the first nine tenders which were called for in this manner are reproduced in Table 18. As tenderers become more familiar with the system and become more experienced in managing targeted labour, the targeted labour goals which are achieved are expected to increase.

Watermeyer and Band (1994), based on information obtained from the Bloekombos project (a pilot project which was undertaken under the National Co-ordinating Committee for Labour Intensive Construction in the Western Cape, prior to the April 1994 election in South Africa, in terms of the Framework
Agreement for Public Works Projects using Labour Intensive Construction Systems (Stofberg 1995), found that approximately 12% of the construction cost was spent on labour drawn from the targeted group. They found from various sources that the accepted cost premium for projects of this nature was between 10 and 15%. This being the case, targeted procurement, based on the preliminary results tabulated in Table 18, appears to be able to deliver the same levels of participation to the target group at a fraction of the cost premium. (It is also interesting to note that the wage levels on the Bloekombos project were just over half of the prevailing statutory minimum wages whereas those in the SMLC were in accordance with the minimum statutory wages.)

Table 18: Recent tender results of 9 municipal capital works projects where use was made of the APP5 specification

<table>
<thead>
<tr>
<th>Contract Description</th>
<th>Tender Value (US$)</th>
<th>Targeted Labour Goal (%)</th>
<th>Cost Premium (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction of water mains</td>
<td>$0.77 m</td>
<td>5 (5)</td>
<td>NIL</td>
</tr>
<tr>
<td>As and when roads and stormwater</td>
<td>$1.10 m</td>
<td>20 (15)</td>
<td>NIL</td>
</tr>
<tr>
<td>Construction of sewers</td>
<td>$0.36m</td>
<td>15 (5)</td>
<td>NIL</td>
</tr>
<tr>
<td>Construction of sewers</td>
<td>$0.26m</td>
<td>25 (5)</td>
<td>8</td>
</tr>
<tr>
<td>Construction of sewers</td>
<td>$0.36m</td>
<td>10 (5)</td>
<td>NIL</td>
</tr>
<tr>
<td>Construction of sewers</td>
<td>$0.58m</td>
<td>10 (5)</td>
<td>NIL</td>
</tr>
<tr>
<td>Construction of sewers</td>
<td>$0.34m</td>
<td>10 (5)</td>
<td>NIL</td>
</tr>
<tr>
<td>Improvement to stormwater drainage</td>
<td>$0.26m</td>
<td>20 (7)</td>
<td>1</td>
</tr>
<tr>
<td>Culvert repair</td>
<td>$0.30m</td>
<td>4 (4)</td>
<td>NIL</td>
</tr>
<tr>
<td>Total</td>
<td>$4.33 m</td>
<td>13 (8)</td>
<td>(0.5)</td>
</tr>
</tbody>
</table>

Notes
1. The minimum targeted labour goal which was set is given in brackets.
2. The cost premium is based on lowest tendered price.
3. 90 points (max) were awarded for price; 10 points (max) were awarded for targeted labour goals.
Tender value excludes VAT and contingencies.

1.4.6 Conclusions

Increased and targeted employment opportunities can be generated in engineering and construction works projects by:

- encouraging the substitution of labour for capital and local resources for imports.
- substituting the use of “labour-friendly” technologies which utilise a higher degree of labour input than is the case for conventional technologies, or are well suited to implementation by small scale enterprises.
- encouraging and developing small scale enterprises to implement employment intensive practices and “labour-intensive” technologies.

Targeted procurement which makes use of human resource specifications and development objective price mechanisms can be used to encourage cost effective employment intensive practices when outsourcing works to the private sector.

Targeted procurement can also facilitate significant levels of participation of targeted small enterprises ranging from labour-only contractors to prime...
contractors. Various contracting strategies associated with targeted procurement can be used effectively to overcome the problems commonly associated with equipping small contractors with specialised or costly items of plant and equipment. It also ensures that any enterprises which are developed in development programmes have access to markets provided that they remain competitive.

Appropriate standards are required to optimise the engagement of smaller contractors and the increase in employment opportunities per unit of expenditure. The measures of quality i.e. conformance to stated requirements, should not involve complex or expensive laboratory procedures. Tests need to be developed to enable quality to be assessed at the point of production upon completion of an activity.

Success in engaging the private sector in labour-based infrastructure works is to a large extent dependent on there being in place appropriate standards and innovative contracting systems.

References


Appendix A: The Dynamic (Drop Weight) Cone Penetrometer

The dynamic (drop weight) cone penetrometer is an instrument which may be used to measure the *in situ* shear strength of a soil. It comprises a drop weight of approximately 10kg which falls through a height of 460mm and drives a cone having a maximum diameter of 20mm (cone angle of $60^\circ$ with respect to the horizontal) into the material being tested.

It is an instrument which has been used for many years in South Africa to evaluate the *in situ* structural condition of a road pavement.

The penetration rate of the DCP, which is proportional to the *in situ* shear strength of the material has been correlated to the CBR of the material (or UCS for cemented materials) by Kleyn et al (1989), is measured in terms of millimetres per blow of the DCP hammer and is called the DCP number (DN). (The value of DN decreases as the strength of the material increases) viz.

\[
\begin{align*}
\text{CBR} & = 410 \times (\text{DN})^{-1.27} \\
\text{UCS} & = 2900 \times (\text{DN})^{-1.09}
\end{align*}
\]

for DN>2.

The DCP has been used in South Africa since the early 1970s in road construction for identifying potentially collapsible soil, construction control, evaluation of the effectiveness of compaction, monitoring stabilised layers and augmenting centreline sampling.
2 TOOLS AND EQUIPMENT — DESIGN, DEVELOPMENT AND SPECIFICATIONS
2.1 THE MART QUESTIONNAIRE ON TOOLS AND EQUIPMENT

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2.1.1 Introduction

The main objectives of the hand tool and intermediate equipment ILO/MART questionnaire, “Labour and Tractor Based Roadworks: Hand tools and Intermediate Equipment” were to:

- obtain data on hand tools used and their performance
- obtain an indication of commonly used items of equipment and their availability
- investigate countries’ equipment manufacturing capacity
- obtain any available standard equipment designs and specifications
- discover the problems associated with the procurement or use of this equipment

The information obtained from these questionnaires would then be used to highlight areas for further work and investigation by the MART programme team, in order to fulfil the project objectives. The results of the questionnaire are discussed below and are a summarised version of MART working papers 2 (equipment) and 8 (hand tools)

2.1.2 Hand Tools

There is general agreement that good quality hand tools are very important to achieving good productivity in labour-based roadworks. On the whole the respondents express satisfaction with the productivity of the hand tools used, presumably meaning that task rates can be achieved in reasonable time and comfort. Therefore, to justify better quality tools of higher cost, task rates would need to be increased. It seems likely that when tools are new and in good condition there may be little difference in productivity of different quality tools, provided shapes and sizes are satisfactory, but as tools wear and distort, the productivity of lower quality tools will drop off more rapidly. However, this cannot be assessed from the questionnaire and is currently being investigated by a series of trials with contractors in Ghana and through the Kisii road training centre in Kenya.

The main criterion used in selecting and procuring hand tools is ready “off-the-shelf” availability. Brands chosen therefore tend to be the more popular, less costly ones widely using in agriculture, often from China or India. However, in some countries, such as Tanzania, tools of satisfactory quality are manufactured locally. Where a number of brands are available, if technical staff handle procurement, brands which best meet specifications tend to be chosen, whereas if a tender board is responsible, there is more emphasis on lower cost. If use of
better quality tools is to be encouraged they would also need to be readily available “off-the-shelf”. This may involve setting up arrangements between suppliers and local stockists and probably guaranteeing a minimum level of sales.

Acceptability testing is generally limited to visual inspection. None of the responses reported any strength or hardness tests as recommended in the ILO Guidelines. In part this was probably due to selection being partly based on previous experience so that there was some knowledge of the performance of the tools. However, if use of better quality hand tools is to be encouraged with more emphasis on meeting specifications, then a higher level of acceptability testing will be needed together with a willingness to reject batches of tools which do not meet specified standards.

The overall impression gained from the questionnaire is that projects “make do” with the hand tools that are readily available and that these are adequate for the task rates set. Assessment of performance may be based on comparisons with what is available rather than against top quality tools. Better quality tools need to be economically justified by:

- a lower “total life” cost (i.e. if the tool costs twice as much, its average life needs to be more than twice as long), and/or
- allowing higher task rates to be set.

### 2.1.3 Intermediate Equipment

The responses to the questionnaire and the discussions at the Accra workshop confirm the serious underdevelopment of the intermediate equipment sub-sector. This significantly constrains the ability of road authorities and contractors to invest in and utilise this type of equipment in the support of labour-based roadworks. The situation is such that many decision makers do not have the knowledge or the supporting environment to make rational and cost efficient decisions regarding whether to use labour, intermediate equipment, or heavy civil engineering plant for each particular activity in the local road sector. Manufacturers and suppliers are also not aware of the exact needs and potential for intermediate equipment to provide optimal solutions for their road authority and contractor clients. The result is that the most cost effective approach is often not achieved.

Furthermore, the natural development progression of a contractor from pure-labour to intermediate equipment to heavy plant, in terms of capital required, management capability, work competence, cash flow and (possibly) profitability is severely constrained.

There is considerable potential for a healthy local industry in the manufacture, fabrication and support of intermediate equipment in many countries (with its related skilled, high-value employment generation) which is currently suppressed by the present situation.

Probably the most serious problem is the lack of cost-awareness regarding the real owning and operating costs of all equipment, and particularly intermediate equipment. Combined with a typical lack of genuine management pressures for cost effective solutions and performance on road authority personnel, there is often little inclination to change to a more rational approach regarding equipment selection and use.
It is apparent that considerable further research, development and promotion of intermediate equipment is required. The principal issues to be addressed from the evaluation of Accra workshop and the equipment questionnaire responses are summarised in the table below.
### Proposed initiatives regarding intermediate equipment

<table>
<thead>
<tr>
<th>Issue</th>
<th>Suggested initiatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lack of awareness regarding intermediate equipment</td>
<td>Develop documentation on the availability, capabilities, flexibility, capital and operating costs, and sourcing of intermediate equipment for clients and contractors. Promote awareness of potential market and requirements with equipment manufacturers and suppliers.</td>
</tr>
<tr>
<td>2. Poor cost-awareness regarding all equipment (particularly intermediate equipment)</td>
<td>Develop owning and operating cost tables for all common items of intermediate equipment and selected comparable heavy items, incorporating factors/assumptions regarding economic life, annual utilisation and capital interest rates.</td>
</tr>
<tr>
<td>3. Non availability of designs and specifications for procurement of intermediate equipment</td>
<td>Develop procurement specifications. Develop designs and prototypes and carry out performance trials for important non off-the-shelf items. Promote development of intermediate equipment with manufacturers and suppliers.</td>
</tr>
<tr>
<td>4. Weak procurement arrangements for intermediate equipment</td>
<td>Develop guidelines on the selection, specification, supplier appointment, quality control, delivery approval, warranty, spares provision and operational support of intermediate equipment.</td>
</tr>
<tr>
<td>5. Poor management and support of intermediate equipment</td>
<td>Develop guidelines on the mechanical support and management of intermediate equipment.</td>
</tr>
<tr>
<td>6. Inadequate training for intermediate equipment</td>
<td>Develop training material regarding all aspects of intermediate equipment. Encourage “mainstreaming” of intermediate equipment training.</td>
</tr>
<tr>
<td>7. Poor availability of finance for intermediate equipment</td>
<td>Encourage donors and programme sponsors to provide suitable credit or financing arrangements (interest rates and terms) for the acquisition and use of intermediate equipment.</td>
</tr>
<tr>
<td>8. Poor availability of intermediate equipment for hire</td>
<td>Encourage establishment of intermediate equipment plant hire companies. Promote projects to support establishment of local, intermediate equipment plant hire companies, instead of equipping all contractors. Encourage contractors to hire out intermediate plant if they do not themselves have work.</td>
</tr>
<tr>
<td>9. Poor dissemination of information about intermediate equipment</td>
<td>Document and disseminate information intermediate equipment to road authorities, practitioners, consultants and contractors through ILO-ASIST, MART, PIARC and professional institutions.</td>
</tr>
</tbody>
</table>

The range of issues to be addressed and the scale of the task means that the initial MART programme will only be able to take the initial steps towards producing the comprehensive documentation and guidelines required concerning intermediate equipment. Priority will be given to documenting the existing knowledge and experiences and developing preliminary guidelines and cost information on the common and priority items of intermediate equipment. Proposals will be developed to improve the knowledge base and dissemination of
issues relating to intermediate equipment and the promotion of its cost-effective use through owning or hiring.

To tackle the crucial issue of increasing cost-awareness and increase general awareness regarding intermediate equipment, a reference document (Intermediate Equipment Handbook) will be developed in the basic format of one double sided A4 sheet for each item of equipment. On the front side of the page will be descriptive details (including illustration/photograph) and recommended procurement specifications for the item including advice on capabilities/limitations and sourcing. On the reverse side will be guidelines on costing. These will be divided into owning costs and operating costs. The owning costs will be set out in a matrix format so that planners, owners or users may select appropriate values of assumed economic life, annual utilisation and finance interest rate to select a corresponding ownership cost per hour or day of use. The operating costs will be calculated separately.

The sheet-per-item format should assist dissemination, training and everyday use of the information, and will ease updating. Contractors, manufacturers or suppliers could request the provision of only the sheet or sheets of immediate interest to them. It should be possible to mail, fax or e-mail this information at very low cost. There is potential to have this information downloadable from the Internet.

It is envisaged that the initial document will be a basic “core” issue. Interested parties will be encouraged to contribute to, expand and refine the data in subsequent issues. The document should help promote the awareness of the potential market with equipment manufacturers. Further funding will be sought to develop the document from the core initial issue.
2.2  APPROPRIATE HAND TOOLS FOR LABOUR-BASED ROADWORKS

Gary Taylor, I.T. Transport, The Old Power Station, Ardington, Near Wantage, OX12 8QJ, Oxon, UK. Email: ittran@rmplc.co.uk

2.2.1 Introduction

Experience shows that labour costs are typically around 40% of the total construction costs in labour-based (LB) roadworks, so that the productivity of the labour force obviously has a significant impact on the cost effectiveness of LB methods.

The main factors governing productivity are the effectiveness of organisation and supervision of LB activities, motivation of the workforce, and the quality and efficiency of the tools and equipment used. The cost of hand tools usually represents 2 to 5% of the total project costs so that a relatively small investment in this element has a substantial impact on the overall cost-effectiveness of the project.

Although accepted standards and specifications for hand tools are available, experience shows that poor quality hand tools are still being widely used in LB projects with a consequent loss of labour productivity. This indicates a need to improve procurement policies and procedures and the ready availability of acceptable quality tools. For instance: increasing awareness of the need for good quality tools; making specifications more readily available and accessible; advocating wider use of simple acceptance tests to check quality; and promoting improved availability of suitable quality tools. These are the aims of the hand tool component of the MART initiative.

This paper reviews the factors affecting hand tool quality and the influence of tool quality and condition on the productivity of LB works. This includes a review of results on the effect of tool wear on productivity from recent tests in Ghana and Kisii, Kenya.

Although there seems to be general agreement by LB practitioners that hand tool quality is very important to the cost-effectiveness of LB work, there appears to be virtually no documented experience to substantiate this view. Hard evidence is needed to prove the case for better quality hand tools to those responsible for procuring and purchasing tools. This seminar brings together a wealth of experience on LB work and the paper would like to take the opportunity to document some of your field experience with hand tools. A questionnaire is included in the paper which it is hoped will draw out some of this valuable experience through responses and additional comments and observations. This kind of evidence is an essential input to promoting the case for good quality hand tools.

2.2.2 Factors Affecting Hand Tool Quality

There are three main factors which affect the quality of hand tools:
1. **Ergonomic efficiency:**

   This is the efficiency and convenience of use of the tool. It is influenced by the shape, size, weight and quality of finish of the tool. For instance, the angle between the blade and handle of a hoe is an important ergonomic factor since it affects the angle at which the blade strikes the soil and hence the efficiency of chopping out the soil.

2. **Strength of the tool:**

   This is the capacity of the tool to perform its required function without deforming excessively or breaking. The important factors are shape, size, material and material treatment (hardening and tempering). The latter is particularly important for impact tools such as hoes and pickaxes since it can double the effective strength of the tool (i.e. the force needed to cause permanent deformation). If tools bend too much or are deformed they do not work as efficiently. If they break then time is lost in repair or replacement. In the worst cases workers may have to restrict their rate of work because of inadequate strength of the tools.

3. **Wear and durability**

   Wear reduces the size of working edges and surfaces and may damage or blunt cutting edges. This reduces the efficiency and productivity of the tools. Durability against abrasive wear appears to depend mainly on the carbon content of the steel, improving with increased carbon content up to about 0.8%. Initial hardness of the metal has less effect.

2.2.3 **Influence of Hand Tools on Cost of Labour-based Work**

   Table 1, derived from an analysis of a number of LB projects in Ghana, Lesotho and the Philippines shows a typical breakdown of LB costs to activities.
Table 1: Typical breakdown of labour costs in labour-based roadworks

<table>
<thead>
<tr>
<th>Activity</th>
<th>Tools used</th>
<th>% Labour cost</th>
<th>% Overall cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning and grubbing</td>
<td>Bush knives, axes, pickaxes</td>
<td>5</td>
<td>1 to 2</td>
</tr>
<tr>
<td>Earthworks:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>excavation</td>
<td>Hoes, pickaxes, mattocks</td>
<td>25-30</td>
<td></td>
</tr>
<tr>
<td>excavation/loading of fill</td>
<td>Shovels</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>haulage of fill</td>
<td>Wheelbarrows</td>
<td>10-15</td>
<td></td>
</tr>
<tr>
<td>spreading/formation</td>
<td>Shovels, hoes, rakes, spreaders</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>total 50-55</td>
<td>20-25</td>
</tr>
<tr>
<td>Excavation of rock</td>
<td>Crow-bars, pickaxes, sledgehammers</td>
<td>up to 12</td>
<td>up to 5</td>
</tr>
<tr>
<td>Gravelling:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>excavation/loading</td>
<td>Pickaxe, hoe, shovel</td>
<td>22.5</td>
<td></td>
</tr>
<tr>
<td>spreading</td>
<td>Rakes, spreader</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>total 30</td>
<td>12</td>
</tr>
</tbody>
</table>

This shows that labour costs typically account for about 40% of total LB costs, with at least half from earthworks. The productivity of earthworks and gravelling activities, making up over 80% of labour costs, is clearly very important to the cost-effectiveness of LB work. The impact of quality on the productivity of the main tools used - hoes, shovels, pickaxes/mattocks, wheelbarrows and rakes/spreaders - is therefore very important. Since the cost of hand tools typically makes up only 2 to 5% of overall construction costs, the labour productivity achieved with the tools is likely to have a significantly greater impact on overall costs than the purchase cost of the tools. This is illustrated by the following simple examples:

1. A heap shovel typically costs about $4 and a good quality shovel 2 to 3 times more, say $10.

   A typical life of a shovel is 100 days, and if the labour cost is $2 per day the labour cost for the life of the shovel is $2 x 100 = $200.

   Therefore to justify changing from a cheap to good quality shovel, a cost increase of $6, the labour cost would need to be cut by $6 i.e. a 3% increase in productivity.

   This is a relatively small increase in productivity which would need to be achieved by increased worker output using the better quality tool and reduced time lost from tool breakages.

2. If the tools are changed twice as frequently, i.e. every 50 days, to reduce losses in productivity from using worn tools, an extra $10 has to be justified over a period of 50 days i.e. an average increase in productivity of 10%.

   In fact the better quality tools will probably last longer so that more time will be available to recoup the extra tool costs and the improvement needed in productivity will be correspondingly reduced.
The extent to which the potential improvements in productivity can be achieved on site depends on labour relations, effectiveness of supervision and the way in which labour is paid:

- **Daily paid:** the output of work completed per day should increase provided there is effective supervision;

- **Task rate:** to achieve improved productivity the daily task rate needs to be increased. The potential for this depends on labour relations and the effectiveness of supervision. Usually there is some flexibility in the daily task rate to allow for variation in soil conditions so that increasing the daily task rate may not be a problem. The Ghana contractor felt that it would be difficult to justify the increase to the workers but other site supervisors have suggested it would not be a problem;

- **Piece work:** improved productivity will increase the volume of work completed per day, but for direct cost savings the unit rate ($ per m or $ per m$^3$) would need to be reduced. This may be difficult to justify to the workers. Although the use of better quality tools may not always produce cost savings from improved productivity, workers will benefit from the reduced time and effort needed to complete their work which should lead to a more contented and better motivated workforce. In addition, there should be savings in site overhead costs from completing work in less time.

### 2.2.4 Field Experience

Most of the documented information on hand tools is concerned with specifications and procurement. No information has been found in project reports reviewing the performance of hand tools and their impact on productivity and project costs. The only documented field experience of the effect of hand tool quality on productivity appears to be from the following test programmes.

#### 2.2.4.1 Tests on hand tool quality in Kenya

A series of tests was carried out by de Veen\(^3\) and others to compare the ergonomic efficiency and strength of farm quality tools with construction quality tools. The only significant difference found in worker productivity with the two types was for hoes, where the construction type hoes gave a 12% higher productivity than the farm type, possibly because they were 25% lighter. However, considerable differences were found in the strength of the two types, the farm type experiencing far more failures, particularly of handles during the tests. Losses in productivity due to broken tools vary very much with working arrangements and availability of replacement tools and are difficult to generalise. However, they are likely to be significant where failure or damage of tools occurs frequently. For instance, in the tests at Kisii (below) it was reported that on some occasions up to 25% extra labour had to be used to go over work which could not be completed to a satisfactory standard on the previous day because of poor quality of tools. Also, in the gravel loading tests, a team of five was reduced to three or four on three out of the nine days because of failure of shovel handles.

#### 2.2.4.2 Tests on the effect of wear of hand tools in Ghana\(^4\)

These tests were carried out as part of the MART programme by a master’s student with considerable support and assistance from a local contractor. The measurements were made in actual site work using shovels and pickaxes in...
ditching and sloping activities. The working force of 12 was split into two groups of six, one group having new tools and the other badly worn tools (about 80 to 90% of maximum wear before the tools would be discarded). The tools are illustrated in Figure 1 and 2. Workers with new and worn tools were located alternately to standardise soil conditions and the new and worn tools were alternated between the groups from day to day. The time to complete the daily task for each worker was recorded, and workers asked for comments on tiredness, the difficulty of the task and the performance of the tools. Three days testing was completed for each task. The average results were as follows:

- **Ditching:** average increase in time for daily task using worn tools = 22%
- **Sloping:** average increase in time for daily task using worn tools = 6%

Ditching is a much more strenuous activity than sloping, involving considerable breaking up of the soil surface, whilst one of the main complaints about the worn tools was the bluntness of the cutting edge of the pickaxes. These factors would explain the greater loss in productivity in the ditching activity.

2.2.4.3 Tests on the effect of wear of hand tools at Kisii, Kenya

These tests have recently been carried out as part of the MART programme to follow up the tests in Ghana. They were implemented by staff at the Kisii Training Centre. In these tests, three groups of tools were compared - new, part worn (about 40% of full wear) and badly worn (80 to 90% of full wear). Two series of tests have been completed as outlined below:

**Series A : Excavation to level tests**

The tests followed the same basic procedure as those in Ghana. The workers were divided into two groups of 10, workers with new and worn tools located alternately and tools exchanged between groups on a daily basis. six days of testing were carried out to compare new and worn tools, and 6 days to compare new and part-worn tools. The main tools used were hoes (jembes) and shovels, with support from mattocks and forked jembes. The average results were as follows:

*Average increase in task time compared to new tools*

<table>
<thead>
<tr>
<th>Tool Condition</th>
<th>Increase in Time (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part-worn tools</td>
<td>+2.5%</td>
</tr>
<tr>
<td>Badly-worn tools</td>
<td>+7%</td>
</tr>
</tbody>
</table>

It was clear in these tests that competition between the workers has a significant effect on the results, with those using the worn tools working considerably harder to keep up with those using the new tools. A scale of tiredness allocating 0 to not tired and 3 to very tired showed a consistent average of +4 “tiredness units” for the Group using worn tools, and +1.8 units for the Group using part-worn tools. The results also showed a clear relationship between “tiredness units” and the time taken to complete the task. Using this relationship 4 units is equivalent to about 52 minutes per worker and 1.8 units to 23 minutes per worker. It therefore seems likely that without the competition (i.e. all workers using worn or part-worn tools) the increase in task time would have been 15 to 20% for the worn tools and 5 to 10% for the part-worn tools.
Series B: Gravel-loading test

In this test the new, part-worn and worn shovels were compared in loading gravel in two quarries. Two teams of five were used in each quarry, one using new shovels and the other part-worn or worn shovels. The tools were exchanged between groups on a daily basis. The total “loading” time during the day was recorded for each group, which comprised 13 trailer loads per group in one quarry and 14 in the other quarry.

The average results were as follows:

Increase in loading time compared to new shovels

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>Increase in Loading Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part-worn shovels</td>
<td>+1%</td>
</tr>
<tr>
<td>Badly-worn shovels</td>
<td>+28%</td>
</tr>
</tbody>
</table>

2.2.4.4 Comments on test results

Shapes and sizes seem to be reasonably the same for most hand tools regardless of quality and it appears that ergonomic efficiency may not be a significant factor affecting productivity.

The main problem experienced with poor quality tools is probably inadequate strength, usually because the tool heads are made of an inferior steel and are not properly hardened and tempered. Inadequate strength may show up as excessive bending or deformation of the tool head or cracking and breaking. Breaking of cheap handles is also a considerable problem. The loss of productivity due to damage and breakages of poor quality hand tools cannot be measured in tests and it is therefore important to collect and collate typical field experience on this issue.

The results of the tests investigating the effect of wear of hand tools on productivity show a consistent pattern. Over the first half of the life of the tool there is little loss in productivity and in fact there may be some benefits from polishing of the surfaces and self-sharpening of cutting edges. In the second half of tool life there is a substantial drop in productivity due to reduced area of working surfaces and damage to cutting edges. It seems that there would be benefits from changing tools at about 60 to 70% of their present life (e.g. at 60 to 70 days instead of 100 days).

For example, consider that three tools costing $10 are used over 200 days instead of two. The increased tool cost of $10 would be justified by an increased productivity of about 7% over the final 33 days of present tool life (i.e. final 33 days of a 100 day life). The tests indicate that increases in productivity of at least 15% are likely.

2.2.5 Proposals for Improving the Quality of Hand Tools Used in Labour-based Roadworks

The MART programme proposes three steps to encourage the wider use of good quality hand tools in LB roadworks:

1. Production of an illustrated brochure to promote the advantages of good quality tools, particularly in terms of cost effectiveness. This will be distributed to organisations and contractors involved in LB work, and
especially to individuals and departments involved in the selection and procurement of hand tools. It is essential to collate field experience to substantiate the brochure.

2. Preparation of hand tool specifications in a clearer and more accessible form. This is likely to be a two page data sheet containing all essential information. It will include details of simple tests that can be carried out on site to check compliance with specifications - a visual inspection to check important features; and a strength test for blade and handle.

3. Informing hand tool suppliers of the potential increase in demand for good quality tools which should be generated by the promotional campaign. It is clear that one of the reasons that projects use lower quality tools is that good quality tools are not always readily available from local suppliers. Promotion of the wider use of good quality tools must therefore be backed up by encouraging suppliers to make the tools readily available.
Figure 1: Comparison of new and worn tools used in this study

New and worn shovels

New and worn pick-axes
Figure 2: Comparison of “worst” tools with new tools

Figure 3: Work in progress
References


Veen, de J (1981) *In collaboration with J Boardman and J Capt*: productivity and durability of traditional improved hand tools for civil construction. ILO/FAO

2.2.6 Appendix: Hand Tools Questionnaire

We need to collate field experience on the impact of hand tool quality on LB productivity and costs to substantiate the case for good quality hand tools. We have been unable to find any documented information and we would therefore be very grateful for any help you can give in providing information from your own experience of LB work through responding to the following questions or through your own comments.

1. Source of field experience

1.1 Country 1.2 Region
1.3 Your Position 1.4 Employer
(job title or responsibility)

Contact details would help us if we wish to follow up any responses:
Name Tel:
Fax E-mail:

2. Sources of documented information

Could you please give details of any documented information that you are aware of on the following topics:

2.1 Feedback from LB projects on the quality and performance of hand tools:

2.2 The impact of hand tool quality on LB productivity and costs.

If the information is contained in project reports, could you please suggest where these may be obtained from.
3. Field experience of handtools

The following refers particularly to problems found with poor quality tools and their impact on productivity.

<table>
<thead>
<tr>
<th>Brand (if known)</th>
<th>Problems encountered and % of tools affected</th>
<th>Impact on productivity and costs</th>
<th>Estimated % loss of productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 Hoes (Jembes)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brands that have been found satisfactory:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical life in months</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.2 Forked hoes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brands that have been found satisfactory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical life in months</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.3 Shovels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brands that have been found satisfactory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical life in months</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.4 Pickaxes/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mattocks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brands that have been found satisfactory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical life in months</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5 Rakes/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>spreaders</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brands that have been found satisfactory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical life in months</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.6 Wheelbarrows</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brands that have been found satisfactory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical life in months</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. Can you provide any information on the comparison of “total life” costs of good and poor quality tools? i.e. costs over the life of the tools taking into account initial cost, costs of repair and replacement and differences in productivity.

5. Do you think the approach outlined in Section 5 of the report to promote the wider use of good quality tools is appropriate/effective?

Do you have any comments on the approach or on the need to promote the use of better quality tools?

6. Do you think good quality tools are important to the productivity and cost-effectiveness of LB roadworks:
Yes No

If yes, on what do you base this opinion? Can you give any practical experience which supports this opinion?

Many thanks for taking the time to think about these issues and for helping us with our project.
Hand Tool Economics

1. Using better quality tools
Typical cost of “cheap” shovel = $4
Typical cost of good quality shovel = $10
Typical life of shovel = 100 days
Typical daily wage = $2
Total labour cost over life of shovel = $200
Increase in productivity to justify spending $6 more on good quality shovel
\[
\frac{6}{200} \times 100 = 3\%
\]
Therefore an increase in hand tool cost of 2.5 times can be justified by an increase in productivity of 3%

2. Changing tools more frequently
If shovel is changed at 1/3 of present life (67 days instead of 100 days) then 3 shovels are used in 200 days instead of 2
Extra cost of shovel = $10
Increase in productivity needed over final 1/3 of present life i.e.
\[
\frac{2 \times 33}{2 \times 66} = \frac{10}{7.5} = 7.5\%
\]
Therefore changing tools at 2/3 of life is justified by an increase in productivity of 7.5%
Tests At Kisii

Series A : Excavation to level

Main Tools : Hoes (jembes); shovels
Support Tools : Forked hoes; mattocks

Loss of productivity compared to new tools
Part-Worn (about 40% worn)  2.5%
Badly-Worn (about 80-90% worn)  7%

Taking into account effect of “competition” between workers, estimated losses in productivity are:
Part-Worn :  5 to 10%
Badly-Worn:  15 to 20%

Series B : Loading gravel

Loss of productivity compared to new shovels
Part-Worn Shovels  1%
Badly-Worn Shovels  28%
2.3 MART WORKING PAPER NO 7: AGRICULTURAL TRACTORS IN ROADWORKS

Robert Petts, B Sc, C Eng, MICE, MIHT, MIAgrE. Intech Associates, © MART

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 three 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:

- hand tools;
- 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.
This document is an output from a project funded by the UK Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of the DFID.

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

---

2.3.1 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 base 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 arrangements.

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 - Unskilled labour wage rates construction sector, 1991
Source: Reference 23
Figure 3 – Average daily wages (Agricultural – 1991)
Source: Reference 24
Figure 3 (cont.) – Average daily wages (Agricultural – 1991)

Source: Reference 24
2.3.2 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)\(^\text{10}\).

On conventional capital intensive road projects, wheeled agricultural tractors are normally used for tasks such as towing compaction rollers and water bowers, 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 focused on works management using a civil service organisation, with the notable exception of the Ghana, Lesotho, Tanzania and Indonesia projects\(^\text{11-14, 22}\). The programmes have usually concentrated on gravel roads (unpaved roads often constitute between 80% to more than 90% of national road networks in EDCs\(^\text{15}\)).

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 a strong argument for better use of local resources\(^\text{6,7,9,15,16}\). 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\(^\text{5}\) force account road maintenance operations. Typically, major road schemes are carried out by international contractors, a few large

---

\(^\text{5}\) Force account: Road authority carrying out works using its own permanent manpower and equipment fleet.
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.

2.3.2.1 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 with sophisticated imported equipment 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 listed 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 environment 27. 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.
Figure 4 - Bitumen pavement reconstruction using tractor harrow (Colas Limited)

Figure 5 - Bituminous overlay using tractor towed asphalt spreader (Intech Associates)
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
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:

<table>
<thead>
<tr>
<th>Earthworks/Unpaved Roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Towed Gravel Haulage Trailer (Figs. 9 &amp; 10)</td>
</tr>
<tr>
<td>• Towed Earth Scraper (dam scoop) (Fig. 11)</td>
</tr>
<tr>
<td>• Towed Drag</td>
</tr>
<tr>
<td>• Towed Water Bowser/ Sprayer (Fig. 12)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Paved Roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Planer/Milling Attachment</td>
</tr>
<tr>
<td>• Towed/Attached Bitumen/Emulsion Heater/Distributor (Fig. 20)</td>
</tr>
<tr>
<td>• Towed Bitumen Slurry Seal Mixer (Fig. 5)</td>
</tr>
<tr>
<td>• Towed Premix Manufacture Equipment</td>
</tr>
<tr>
<td>• Towed Bitumen Mix Spreader (Fig. 5)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>General Roadworks Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Heavy Duty Automatic Pick-up Hitch</td>
</tr>
<tr>
<td>• Light Towed Grader (Up to 3 Tonnes) (Figs. 13 &amp; 16)</td>
</tr>
<tr>
<td>• Heavy Towed Grader (Over 3 Tonnes) (Figs. 14 &amp; 15)</td>
</tr>
<tr>
<td>• Lime/Cement/Bitumen/Mechanical Stabilisation Harrow/Mixer Attachments (Figs. 4 &amp; 16)</td>
</tr>
<tr>
<td>• Towed Rubber Tyre Roller</td>
</tr>
<tr>
<td>• Towed Steel Wheel Roller (dead-weight/vibrating) (Fig. 17)</td>
</tr>
<tr>
<td>• Front End Loader Attachment (Figs. 4 &amp; 16)</td>
</tr>
<tr>
<td>• Ripper Attachment (Fig. 15)</td>
</tr>
<tr>
<td>• Towed Accommodation/Workshop Caravans</td>
</tr>
<tr>
<td>• Towed Fuel Bowser</td>
</tr>
<tr>
<td>• Towed/Attached Concrete Mixer</td>
</tr>
<tr>
<td>• Towed Compressor and Pneumatic Tools</td>
</tr>
<tr>
<td>• Towed Mobile Stone Crushers and Screens</td>
</tr>
<tr>
<td>• Rotary Grass Cutter</td>
</tr>
<tr>
<td>• Powered Sweeper/Broom (Figs. 19 &amp; 20)</td>
</tr>
<tr>
<td>• Low Loader Trailer (Fig. 18)</td>
</tr>
</tbody>
</table>

**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 Kenya 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 those incurred using heavy plant.
Figure 9: 3 cubic metre gravel haulage trailer for labour loading and unloading (Tinto)

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 (Arthur Garden)

Figure 14: 5 tonne heavy towed grader (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 dead-weight 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 regравelling 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 co-operation 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

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit capital cost new # (US$)</th>
<th>No. in fleet</th>
<th>Item capital cost (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracked loading shovel (cat 953)#</td>
<td>215,000</td>
<td>1</td>
<td>215,000</td>
</tr>
<tr>
<td>Tipper 4x2 7t ##</td>
<td>55,000</td>
<td>5</td>
<td>275,000</td>
</tr>
<tr>
<td>Motorgrader (cat 140)</td>
<td>250,000</td>
<td>1</td>
<td>250,000</td>
</tr>
<tr>
<td>Self propelled roller</td>
<td>85,000</td>
<td>1</td>
<td>85,000</td>
</tr>
<tr>
<td>Fuel bowser truck</td>
<td>60,000</td>
<td>1</td>
<td>60,000</td>
</tr>
<tr>
<td>Water bowser truck</td>
<td>55,000</td>
<td>1</td>
<td>55,000</td>
</tr>
<tr>
<td>Service truck</td>
<td>60,000</td>
<td>1</td>
<td>60,000</td>
</tr>
<tr>
<td>Supervision pick-up</td>
<td>20,000</td>
<td>1</td>
<td>20,000</td>
</tr>
<tr>
<td><strong>Total US$</strong></td>
<td><strong>1,020,000</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

1. Basic tractor equipment for routine maintenance

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Cost (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>55hp (41kW) 4x2 agricultural tractor</td>
<td>22,000</td>
</tr>
<tr>
<td>5t fixed body heavy duty trailer</td>
<td>6,000</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td><strong>28,000</strong></td>
</tr>
<tr>
<td>Optional 2t towed grader</td>
<td>8,000</td>
</tr>
<tr>
<td>Optional towed water bowser</td>
<td>8,000</td>
</tr>
<tr>
<td>Optional pedestrian vibrating roller</td>
<td>12,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>56,000</strong></td>
</tr>
</tbody>
</table>

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

2. Basic tractor equipment for earth/gravel road reconstruction

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Cost (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 No 100hp (75kW) 4X4 agricultural tractors</td>
<td>100,000</td>
</tr>
<tr>
<td>2 No 5t heavy towed graders</td>
<td>80,000</td>
</tr>
<tr>
<td>1 No towed dead-weight roller with transport wheel</td>
<td>25,000</td>
</tr>
<tr>
<td>1 No towed fuel bowser</td>
<td>8,000</td>
</tr>
<tr>
<td>1 No towed water bowser</td>
<td>8,000</td>
</tr>
<tr>
<td>1 No pickup truck</td>
<td>20,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>241,000</strong></td>
</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th>Cost (US$ equivalent)</th>
<th>For 100 km of road</th>
<th>For 150 km of road</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Second-hand pick-up</td>
<td>8,000</td>
<td>8,000</td>
</tr>
<tr>
<td>Assumed life of 4 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Bicycles @ 1 per 15 Km</td>
<td>700</td>
<td>1,000</td>
</tr>
<tr>
<td>Each cost US$ 100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assumed life of 3 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office Furniture</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>Assumed life of 10 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/H Typewriter</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Assumed life of 4 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand tools stock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- store &amp; issued (numbers in brackets for 100/150km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hoes (55/80) @US$ 3.5</td>
<td>193</td>
<td>280</td>
</tr>
<tr>
<td>Shovels (55/80) @US$ 7.0</td>
<td>385</td>
<td>560</td>
</tr>
<tr>
<td>Bush knives (55/80) @US$ 3.5</td>
<td>193</td>
<td>280</td>
</tr>
<tr>
<td>Slashers (55/80) @US$ 3.5</td>
<td>193</td>
<td>280</td>
</tr>
<tr>
<td>Rakes (55/80) @US$ 4.0</td>
<td>220</td>
<td>320</td>
</tr>
<tr>
<td>Sharpening files (55/80) @US$ 3.0</td>
<td>165</td>
<td>240</td>
</tr>
<tr>
<td>Wheelbarrows (4/6) @US$ 50.0</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>Hand rammers (7/11) @US$ 10</td>
<td>70</td>
<td>110</td>
</tr>
<tr>
<td>Culvert tools (7/11) @US$ 10</td>
<td>70</td>
<td>110</td>
</tr>
<tr>
<td>Mason’s hammers (7/11) @US$ 5</td>
<td>35</td>
<td>55</td>
</tr>
<tr>
<td>Mattocks (7/11) @US$ 6</td>
<td>42</td>
<td>66</td>
</tr>
<tr>
<td>Axes (7/11) @US$ 5</td>
<td>35</td>
<td>55</td>
</tr>
<tr>
<td>Crow bars (2/3) @US$ 6</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>Sledge hammers (2/3) @US$ 10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Pickaxes (2/3) @US$ 10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Claw hammers (2/3) @US$ 10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Tape measures (7/11) @US$10</td>
<td>70</td>
<td>110</td>
</tr>
<tr>
<td>Ditch templates (7/11) @US$ 10</td>
<td>70</td>
<td>110</td>
</tr>
<tr>
<td>Camber boards (7/11) @US$ 10</td>
<td>70</td>
<td>110</td>
</tr>
<tr>
<td>Spirit levels (7/11) @US$ 10</td>
<td>70</td>
<td>110</td>
</tr>
<tr>
<td>Boning rods (1 set) @US$ 15</td>
<td>15</td>
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<tr>
<td>Line &amp; level (1 set) @US$ 8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Totals (US$)</td>
<td>11,526</td>
<td>12,877</td>
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</tbody>
</table>

*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.

2.3.2.2 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.

2.3.2.3 Plant hire

Bank interest rates in developing countries are usually high (15 - 48% in the countries surveyed by MART Working Paper No 28). 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 the 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

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Labour with picks, mattocks, sledgehammers, crowbars, shovels</td>
<td>Labour with sledgehammers, stone hammers and steel mesh</td>
<td>Labour using fixed volume containers per unit area</td>
<td>Labour with one barrel hand lance</td>
<td>Labour with rakes and shovels</td>
<td>Labour with twin drum pedestrian vibrating roller</td>
<td>Level and thickness control</td>
</tr>
<tr>
<td></td>
<td>Labour with compressor and breaker tools</td>
<td><em>Wheeled tractor with adapted towed roller</em></td>
<td>Labour with one barrel hand lance</td>
<td><em>Wheeled tractor with reciprocating harrow</em></td>
<td><em>Wheeled tractor with heavy towed grader</em></td>
<td><em>Wheeled tractor with heavy towed roller</em>**</td>
<td>Grading – sieve analysis</td>
</tr>
<tr>
<td></td>
<td><em>Wheeled tractor with pulveriser/milling attachment</em></td>
<td><em>Wheeled tractor with adapted towed roller</em></td>
<td>Labour with one barrel hand lance</td>
<td><em>Wheeled tractor with heavy towed grader</em></td>
<td>Motor grader</td>
<td><em>Wheeled tractor with heavy towed roller</em>**</td>
<td>Voids</td>
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<tr>
<td></td>
<td><em>Wheeled tractor with pulveriser/milling equipment</em></td>
<td><em>Wheeled tractor with pulveriser/milling attachment</em></td>
<td>Labour using fixed volume containers per unit area</td>
<td><em>Wheeled tractor with heavy towed grader</em></td>
<td>Motor grader</td>
<td><em>Wheeled tractor with heavy towed roller</em>**</td>
<td>Bitumen content</td>
</tr>
<tr>
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<td><em>Wheeled tractor with pulveriser/milling equipment</em></td>
<td><em>Wheeled tractor with pulveriser/milling equipment</em></td>
<td>Labour using fixed volume containers per unit area</td>
<td><em>Wheeled tractor with heavy towed grader</em></td>
<td>Motor grader</td>
<td><em>Wheeled tractor with heavy towed roller</em>**</td>
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<td><em>Wheeled tractor with heavy towed grader</em></td>
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<td><em>Wheeled tractor with heavy towed roller</em>**</td>
<td>Deflectometer</td>
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---

* 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 subbase are of acceptable characteristics and any necessary repairs to the drainage system are carried out.

Source: Intech Associates
**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

<table>
<thead>
<tr>
<th>First Coat</th>
<th>Second Coat</th>
<th>Optional Slurry Seal</th>
</tr>
</thead>
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<td>1. Apply First Seal Coat</td>
<td>2. Apply Stone Chippings (20/14 mm)</td>
<td>3. Apply Second Seal Coat</td>
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<td>Labour using fixed volume containers per unit area</td>
<td>Labour by hand from wheeled tractor towed trailer</td>
<td>Labour using fixed volume containers per unit area</td>
</tr>
<tr>
<td>Labour with one barrel hand lance</td>
<td>Labour by hand from truck</td>
<td>Labour with one barrel hand lance</td>
</tr>
<tr>
<td>Wheeled tractor with towed/attached bitumen distributor</td>
<td>Tipper truck with tailgate chipper</td>
<td>Wheeled tractor with Towed/attached bitumen distributor</td>
</tr>
<tr>
<td>Truck mount distributor</td>
<td>Self-propelled chipping spreader</td>
<td>Truck mounted slurry mixer</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour by hand from wheeled tractor towed trailer</td>
<td>Labour with concrete mixer</td>
<td>Labour with concrete mixer</td>
<td></td>
</tr>
<tr>
<td>Wheeled tractor and towed concrete mixer</td>
<td>Light compaction by tractor towed or self propelled rubber tyred or deadweight drum roller, ensuring that stone chippings are not crushed</td>
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<td></td>
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<tr>
<td>Truck mounted concrete mixer</td>
<td>Optional 3rd coat to form a ‘Cape Seal’</td>
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<td></td>
</tr>
<tr>
<td>Tractor or truck towed slurry box</td>
<td>Bitumen rate of spread</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truck mounted slurry distributor</td>
<td>Visual inspections</td>
<td></td>
<td></td>
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<tr>
<td>Tipper truck with tailgate chipper</td>
<td>Chipping sizes and cleanliness</td>
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<tr>
<td>Self-propelled chipping spreader</td>
<td>Stone material</td>
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</table>

* 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.
2.3.3 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 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.

2.3.4 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.

2.3.5 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.
References


2. Petts, R. C. 1995. Technology development in road construction and maintenance for developing countries Paper for the Conference on Science and Technology in Third World Development, University of Strathclyde


21. Technical Data Sheet no 9 & no 10, Road Emulsion Association, UK.


Annex 1

Supporting Labour Cost Data

The data in this Annex has been used to prepare the Figures 2 & 3 in the main text.
## Figure 2 – Unskilled Labour Wage Rates 1991 – Construction Sector

Europe & Selected Economically Developed Countries

### January 1991 wage rates

<table>
<thead>
<tr>
<th>Country</th>
<th>Local Currency</th>
<th>Unskilled wage rate</th>
<th>Exchange rate US$1 = Local currency</th>
<th>Hourly wage rate US$ equivalent</th>
<th>Daily wage rate US$ equivalent*</th>
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**Notes**

*Assumes a 7 hour day

** Semi-skilled labourer

The cost of employing labour can be more than doubled by the mandatory and voluntary additional payroll costs.

The wage rates are usually quoted for work in the capital city.
Figure 3 – Average Daily Agricultural Wages, 1991

Table 1

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Table 2

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</table>
Notes

Exchange rates: Financial Times 20 August 1991, unless otherwise indicated

1 Monthly rates divided by 25
2 1987 data
3 Weekly rate divided by 6
4 1990 data
5 1988 data
6 1993 data
7 Hourly rates times 7
8 1989 data
9 Skilled workers
10 Forestry
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 uneconomic. 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:-

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Motorgrader</th>
<th>Towed Grader</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finance Interest Charge</td>
<td>20% per annum</td>
<td>20% per annum</td>
</tr>
<tr>
<td>Purchase Cost assumed in Tables A &amp; B</td>
<td>US$ 200,000</td>
<td>US$ 90,000</td>
</tr>
<tr>
<td>Actual Purchase Cost (adjustment)</td>
<td>US$ 195,000</td>
<td>US$ 88,000</td>
</tr>
<tr>
<td>Economic Life</td>
<td>12 years</td>
<td>10 years</td>
</tr>
<tr>
<td>Annual Utilisation (hours)</td>
<td>600 (e.g. 100 days @ 6 hours)</td>
<td>800 hours</td>
</tr>
</tbody>
</table>

Other annual utilisation assumptions were used to plot Figure 7.
COST CALCULATION 120 Hp MOTORGRADER

Sheet 1

Total hourly charge comprises ownership + operating + overhead costs

Ownership costs comprise:–

Depreciation/replacement (table A1) plus finance charge (table B1, B2 or B3)

All table A & B costs in US$/hour

Cost new – US$ 200,000 (including all taxes, duties, CIF & delivery charges)

Ownership, operating and overhead costs are calculated on sheet 2:–

<table>
<thead>
<tr>
<th>Economic Life Years</th>
<th>Utilisation in Hours/Year</th>
<th>A-1 – Depreciation/Replacement Charge in US$/Hour</th>
<th>B1 – Finance @ 10%</th>
<th>B2 – Finance @ 20%</th>
<th>B3 – Finance @ 30%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>200</td>
<td>400</td>
<td>600</td>
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<td>167</td>
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<td>83</td>
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<td></td>
<td>83</td>
<td>42</td>
<td>28</td>
<td>21</td>
</tr>
</tbody>
</table>

Ownership, operating and overhead costs are calculated on sheet 2:-
COST CALCULATION

CONVERSION TO DAILY CHARGE RATE

OWNERSHIP COSTS

C ADJUSTMENT FOR ACTUAL COST OF PURCHASE
Selected Depreciation/replacement charge (US$/hr) from Table A1 28 (C1)
Selected Finance charge (US$/hr) from Table B1, B2 or B3 36 (C2)
Actual purchase/replacement cost in US$ 195,000 (C3)
Assumed number of operating hours per day 6 (C4)

DAILY OWNERSHIP COST = (C1 + C2) x C4 x C3 / 200,000 = US$/day 374.4

D ADJUSTMENT FOR EXPECTED RESIDUAL/SCRAP VALUE (IF ANY)
Assumed Residual/Scrap Value in US$ 10,000 (D1)
Assumed Economic Life in years 12 (D2)
Assumed Utilisation in Hours/Year 600 (D3)

ADJUSTMENT FOR SCRAP VALUE = (D1 x C4) / (D2 x D3) US$/day 8.3

X = 366.1

OPERATING COSTS

E SPARES & CONSUMABLES
Either predict daily costs from past records or select from the following:-
Select percentage of spares and consumables per year compared to machine cost new,
Suggested value between 5% and 12% (usually increases with age) 8 % (E1)

DAILY COST OF SPARES = 0.01 x C3 x C4 x E1 / D3 US$/day 156.0

F SERVICING AND REPAIR (WORKSHOP LABOUR COSTS)
Either predict daily costs from past records or select the following:-
Suggested value between 25% and 100% of (E) US$/day 39.0

G FUEL & LUBRICANTS
Cost of fuel per litre (add between 2 and 5% to cover lubricant costs) 0.4 (G1)
Assumed fuel consumption in litres per hour 18 (G2)

DAILY FUEL COST = C4 x G1 x G2 US$/day 43.2

H OPERATORS (DAILY COSTS)

<table>
<thead>
<tr>
<th>Operator</th>
<th>Wages</th>
<th>Allowances</th>
<th>Other</th>
</tr>
</thead>
<tbody>
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<tr>
<td>Banksman</td>
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<td></td>
</tr>
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</table>

Subtotals 18 8 3 US$/day 29.0

Y = 267.2

OVERHEADS (& PROFIT)

Predict from past records to include:-
Offices, Workshops, Tools & other Facilities
Supervisory, management and clerical personnel
Supervision and support vehicles
Stores and other stock
Insurances
Banking and other finance charges not relating to the equipment item
Admin, training, safety or other overhead costs
Risk, late payment and other contingency items
Profit

SUB-TOTAL FOR OVERHEADS AND PROFIT 200.0

Z = 200.0

TOTAL COST TO BE CHARGED = X + Y + Z US$/day 833.3

NOTES

1 Finance charge (overleaf) calculated by the formula:
C2 = ((N + 1) / 2N) x Purchase Price x Interest rate expressed as a decimal

Hours per year
Where N = number of years (economic life)

Ref: costs1bb
TOTAL HOURLY CHARGE COMPRISES OWNERSHIP + OPERATING + OVERHEAD COSTS

OWNERSHIP COSTS COMPRISE:-
DEPRECIATION/REPLACEMENT (TABLE A1) PLUS FINANCE CHARGE (TABLE B1, B2 OR B3)

COST NEW - US$ 90,000 (INCLUDING ALL TAXES, DUTIES, CIF & DELIVERY CHARGES)

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<th>A1 – DEPRECIATION/REPLACEMENT CHARGE IN US$/HOUR</th>
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<table>
<thead>
<tr>
<th>B3 – FINANCE @ 30% FINANCE CHARGE IN US$/HOUR</th>
<th>ECONOMIC LIFE YEARS</th>
<th>UTILISATION IN HOURS/YEAR</th>
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<tbody>
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</table>

OWNERSHIP, OPERATING AND OVERHEAD COSTS ARE CALCULATED ON SHEET 2:-
COST CALCULATION

Continued SHEET 2

CONVERSION TO DAILY CHARGE RATE

OWNERSHIP COSTS

<table>
<thead>
<tr>
<th>C</th>
<th>ADJUSTMENT FOR ACTUAL COST OF PURCHASE</th>
<th>100 hp 4WD TRACTOR + TOWED GRADER (5t)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Selected Depreciation/replacement charge (US$/hr) from Table A1</td>
<td>11 (C1)</td>
</tr>
<tr>
<td></td>
<td>Selected Finance charge (US$/hr) from Table B1, B2 or B3</td>
<td>12 (C2)</td>
</tr>
<tr>
<td></td>
<td>Actual purchase/replacement cost in US$</td>
<td>88,000 (C3)</td>
</tr>
<tr>
<td></td>
<td>Assumed number of operating hours per day</td>
<td>6 (C4) local currency</td>
</tr>
<tr>
<td></td>
<td>DAILY OWNERSHIP COST = (C1 + C2) x C4 x C3 / 90,000</td>
<td>US$/day 134.9 (C)</td>
</tr>
</tbody>
</table>

D | ADJUSTMENT FOR EXPECTED RESIDUAL/SCRAP VALUE (IF ANY) |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Assumed Residual/Scrap Value in US$</td>
</tr>
<tr>
<td></td>
<td>Assumed Economic Life in years</td>
</tr>
<tr>
<td></td>
<td>Assumed Utilisation in Hours/Year</td>
</tr>
<tr>
<td></td>
<td>ADJUSTMENT FOR SCRAP VALUE = (D1 x C4) / (D2 x D3)</td>
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<tr>
<td></td>
<td>SUB-TOTAL FOR OWNERSHIP COSTS</td>
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OPERATING COSTS

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<tr>
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<th>SPARES &amp; CONSUMABLES</th>
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</thead>
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<tr>
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<td>Either predict daily costs from past records or select from the following:-</td>
</tr>
<tr>
<td></td>
<td>Select percentage of spares and consumables per year compared to machine cost new.</td>
</tr>
<tr>
<td></td>
<td>Suggested value between 5% and 12% (usually increases with age)</td>
</tr>
<tr>
<td></td>
<td>DAILY COST OF SPARES = 0.01 x C3 x C4 x E1 / D3</td>
</tr>
</tbody>
</table>

F | SERVICING AND REPAIR (WORKSHOP LABOUR COSTS) |
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Either predict daily costs from past records or select the following:-</td>
</tr>
<tr>
<td></td>
<td>Suggested value between 25% and 100% of (E)</td>
</tr>
</tbody>
</table>

G | FUEL & LUBRICANTS |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost of fuel per litre (add between 2 and 5% to cover lubricant costs)</td>
</tr>
<tr>
<td></td>
<td>Assumed fuel consumption in litres per hour</td>
</tr>
<tr>
<td></td>
<td>DAILY FUEL COST = C4 x G1 x G2</td>
</tr>
</tbody>
</table>

H | OPERATORS (DAILY COSTS) |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Operator</td>
</tr>
<tr>
<td></td>
<td>Operator</td>
</tr>
<tr>
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<td>Assistant</td>
</tr>
<tr>
<td></td>
<td>Banksman</td>
</tr>
<tr>
<td></td>
<td>Subtotals</td>
</tr>
<tr>
<td></td>
<td>US$/day</td>
</tr>
<tr>
<td></td>
<td>SUB-TOTAL FOR OPERATING COSTS</td>
</tr>
</tbody>
</table>

OVERHEADS (& PROFIT) |

Predict from past records to include:- |

| Offices, Workshops, Tools & other Facilities |
| Supervisory, management and clerical personnel |
| Supervision and support vehicles |
| Stores and other stock |
| Insurances |
| Banking and other finance charges not relating to the equipment item |
| Admin, training, safety or other overhead costs |
| Risk, late payment and other contingency items |
| Profit | local currency |
| SUB-TOTAL FOR OVERHEADS AND PROFIT | 100.0 |

TOTAL COST TO BE CHARGED = X + Y + Z | US$/day 383.2 |

NOTES

1 Finance charge (overleaf) calculated by the formula:-

\[
C2 = \left(\frac{(N + 1)}{2N}\right) \times \text{Purchase Price} \times \text{Interest rate expressed as a decimal}
\]

Where N = number of years (economic life)

Ref: costs2bb
Annex 3

Manufacturer’s details

Arthur Garden Engineering
Tel: Int + 263 4 754272  Fax: Int + 263 4 754274

Colas Limited
Rowfant, Crawley, West Sussex, RH10 4NF, UK.
Tel: Int. + 44 (0) 1342 711000  Fax: Int. + 44 (0) 1342 711198/99  e-mail: StevenStJ@colas-ltd.demon.co.uk

The Phoenix Engineering Company Ltd
Phoenix Works, Chard, Somerset, TA 20 1JE, UK.
Tel: Int. + 44 (0) 1460 63531/2/3 Fax: Int. + 44 (0) 1460 67388

Reynolds International Inc
P O Box 550, McAllen, Texas 78505, USA.
Tel: Int + 1 210 687 7500  Fax: Int. + 1 210 630 5263

Simba International Ltd
Woodbridge Road, Sleaford, Lincolnshire, NG34 7EW, UK.
Tel: Int. + 44 (0) 1529 304654  Fax: Int. + 44 (0) 1529 413468

TBF Thompson (Engineering) Ltd
6-10 Killyvalley Road, Garvagh, Coleraine, Co. Londonderry, Northern Ireland, BT51 5JZ, UK.
Tel: Int. + 44 (0) 12665 58771  Fax: Int. + 44 (0) 12665 58906

Tinto
Hästt Zimbabwe, No 6 Nuffield Road, P O Box 2356, Harare, Zimbabwe.
Tel: Int + 263 4 756445/9  Fax: Int + 263 4 64726, 754333/6; 757000/3;

Turbomech
Cooper Motor Corporation, Agricultural Division, P O Box 30135, Nairobi, Kenya.
Tel: Int + 254 2 544505  Fax: Int + 254 2 542543
2.4 DEVELOPMENT OF APPROPRIATE COMPACTION EQUIPMENT FOR LABOUR-BASED GRAVELLING OPERATIONS

Carl-Eric Hedström, Chief Technical Advisor, Labour-Based Component, Roads Training School, Roads Department, Zambia

2.4.1 Background

The Labour-based Road Improvement and Maintenance Project in the Northern Province of Zambia was transferred to Lusaka in June 1994. This project had been operational in Northern Province for about seven years under a NORAD supported Agricultural and Rural Development Programme.

The main objectives were to demonstrate and establish labour-based methods of road construction and maintenance by improving access to agriculturally productive areas in Northern Province.

The type of roads worked on were in most cases unclassified low traffic volume roads with a four metre carriageway. Compaction was achieved through a combination of natural consolidation and traffic compaction, or in exceptional cases by very light rollers for initial compaction.

However, in Lusaka, the Labour-based Project is part of a NORAD supported Road Sector Programme. It operates under the auspices of the Roads Department on classified roads, whose specification and traffic loads in most cases require compaction of the gravel layer.

2.4.2 The Challenge

The project operates a fleet of tractor-towed light equipment for road works. This equipment includes tractor-towed trailers (designed in Kenya with support from ASIST6), water bowser (from Tinto Ltd) and compaction rollers (project designed). When we commenced our operations in Lusaka we borrowed pedestrian vibrating rollers from the Provincial Road Engineer (PRE) in Lusaka. These rollers had been left behind by an earlier phased-out labour-based project. We also immediately placed an order for two new pedestrian vibrating rollers, assuming that this type of equipment must be well tested since it is widely used on labour-based projects. However, after only six months of use, they started having frequent breakdowns. These were caused by the unfamiliarity of the operators with the precision of operation and maintenance required, and a concomitant shortage of mechanics who were familiar with the complexity of the machine. A great deal of down time was also spent awaiting the arrival of spare parts ordered

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6 See Designs and specifications for a standard trailer and hitch for labour-based works, ILO/ASIST, 1996
from Europe or South Africa at exorbitant prices for quick delivery. It should be understood that we do not have a country agent for this equipment and consequently there is neither a stock of spare parts nor mechanics in Zambia acquainted with pedestrian vibrating rollers.

It thus became very clear to the labour-based project staff that an alternative to this machine needed to be investigated. On the one hand, they recognised that a pedestrian vibrating roller provides a lot of flexibility to the work planner, and its use can be justified under certain circumstances. This is especially true when the agricultural tractor concept for towing of trailers, water bowers etc. is not an option due to haulage distances beyond the economical use of tractors and trailers; or when the tractor would only be used for towing a roller. The pedestrian vibrating roller can also be justified on steep gradients, or when particular soil types cannot be economically compacted without a vibrating roller. But on the other hand, since Zambia is predominantly flat and blessed with reasonably good natural soils (except for areas in Western and North-western Provinces, which have very difficult sandy soils of the type often found in Botswana), pedestrian vibrating rollers were not considered essential. This is especially true for gravelling works on a contractor development programme where durability is essential in order to allow the emerging contractor to meet production targets and to be able to repay the equipment loan in a reasonable period of time.

The experiences outlined above are apparently also shared by other labour-based practitioners. They are areas of concern in many other countries and were very clearly expressed in a paper presented at the Fifth Regional Seminar for Labour-based Practitioners held in Ghana in April, 1996 by Henry Danso from the Department of Feeder Roads, Koforidua, Ghana. In his paper entitled Factors influencing the output of labour-based contractors in Ghana he states:

Frequent Breakdown of Rollers:

In most rural areas, the back-up services required to minimise the problems posed by the frequent breakdown of the vibratory rollers are not available. Where mechanics are available, they are not adequately equipped to deal with the problem. This, coupled with the non-availability of spares on the market within the vicinity of the sites, has resulted in utilisation rates falling below 50%, thus affecting the performance of the contractor. In some instances, the breakdown of rollers leads to suspension of earthworks and gravelling for more than two months.

2.4.3 Meeting the Challenge

Needless to say we share the views of Eng Danso on this subject, and hence the need to develop an alternative to pedestrian vibrating rollers. In our Contractor Development Programme for rehabilitation contractors, we are using the platform
method for rehabilitation works\(^7\). This means that compaction is sometimes required at four stages, subgrade, plug, camber formation, and gravelling. If 100% gravelling is required on a five metre wide carriageway, and if the production target is 2km per month, then 1,500m\(^3\) of gravel will have to be compacted per month in addition to the subgrade, plug, and camber formation. This totals 15,000m\(^3\) of gravel per year (ten months of production). In a project where the repayment period for a fleet of equipment on loan to the contractor has been set at four years, this amount of gravelling totals 60,000m\(^3\) over the four years. Moreover, in this scenario, it is assumed that no piece of equipment will be replaced during this four year period. Hence the need for well designed, very durable and appropriate equipment.

Admittedly, one has to be a much better work planner when using tractor-towed dead-weight rollers which have to share tractor time with trailers and bowser, than if one has a number of pedestrian vibrating rollers at one’s disposal. But with good daily planning of the use of the tractor, it is possible to maintain a good production even with a tractor-towed roller, if the tractor-shared operations are well planned. This means watering very late in the afternoon up to sunset in order for the gravel to retain its moisture over the night. Rolling then starts early in the morning with an ideal moisture content. Thereafter, the tractor is used for hauling of gravel, that is during the middle of the day. However, if the natural gravel contains sufficient moisture, it should be heaped along the road and not spread. In this way the gravel will retain its moisture while a sufficient quantity of material is piled up to justify bringing along the roller.

### 2.4.3.1 Roller design parameters

We were thus determined to design a tractor-towed dead-weight roller with good production capacity. It had to be very robust and with a higher weight to width roller ratio (linear load) than we had earlier seen used on labour-based projects. We had in mind a ratio of 3 tonnes per metre drum width. This would give a total ballasted weight of about 4.5 tonnes and, when empty, a weight of 1.5 tonnes. This would make it easy to transport.

We should like to mention here that the inspiration to design and locally manufacture this type of roller came from the Training Modules from Thailand, and from CTP 64 Pilot project on labour-based road construction and maintenance in Thailand – Compaction by labour compatible equipment by Lars Karlsson.

**Roller (1): Single drum**

The first roller was designed with the following dimensions/specifications:

<table>
<thead>
<tr>
<th>Function</th>
<th>Dead-weight roller to be pulled by a 60 - 70 hp agricultural tractor. In mountainous areas the tractor should preferably be equipped with four-wheel drive. In undulating terrain it is sufficient to improve traction by</th>
</tr>
</thead>
</table>

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\(^7\) This involves forming a level platform (the subgrade) before excavating the drains, and the inner and outer slopes, to build up the road pavement in stages. The first stage is to form a "plug” in the centre of the road by excavating material from the side drains. This plug will generally be half the height (at the centre) of the final camber.
filling the rear tyres with water (75%) and by ballasting the front of the tractor using front-end weights or water.

**Overall design**

A hollow steel roller mounted in a frame, with a towing bar attached, and with a steel bucket sitting on top of the frame

**Transportation**

Shipping weight is 1,700kg

Can be loaded onto the ASIST-promoted trailer; or transported on a specially built low-bed trailer as used for pedestrian vibrating-rollers; or by attached transport wheels (currently under design); or of course on a truck.

**Operating weight**

Empty is 17,00kg; ballasted with water in the drum is 2,600kg; and fully ballasted with water and stone is approximately 4,500kg.

The ‘bucket over a drum’ design feature allows for a number of weight combinations, and an initial pass can be made with a lower weight, thus avoiding material being pushed in front of the steel drum.

**Volume of bucket**

Approximately 1.2m³. Ballasted with soil this gives an added weight of about 2 tonnes.

**Drum dimensions**

Single drum diameter is 1,000mm and width is 1,200mm; volume is 0.94m³. Manufactured from 20mm thick steel plate.

The drum can be ballasted with water, which gives an added weight of 940kg.

**Compaction characteristics**

Static linear load (empty) = 1.4 tonne/m
Static linear load (filled with water) = 2.2 tonne/m
Static linear load fully ballasted = 3.87 tonne/m

**Manoeuvrability**

Outer turning radius when tractor is attached is rather large (about 4.25m) which means turning on a typical feeder road is time consuming and difficult if the side slopes are not used. Therefore, the drawbar arrangement of Roller (2), with a detachable drawbar which can be fixed at both front and rear ends is to be preferred. Working speed is maximum 3km/hour. Transport speed (towed) is maximum 10km/hour

**Manufacturing and cost**

The roller was locally manufactured in Lusaka by a mechanical engineering firm. The cost was US$ 3,705 including development costs (but not including project staff costs). This roller was delivered in April 1995 and has been in operation ever since, without any breakdown. Hence the design parameters seem appropriate for its purpose.

**Performance**

The roller has fulfilled all expectations when it comes to achieved compaction results. This proves that the chosen linear load was correctly assumed. Its durability has also been exemplary as it has been virtually maintenance free for two years. The only parts which eventually would have to be replaced are the bearings. However, if they are regularly greased they should last for some years if not towed at too high a speed from the site of operations to the camp.

**Performance indicators**

Testing method: as per BS 1377 - 1990 modified procedures and methods (sand replacement method/Modified Proctor).

General soil characteristics: sandy lateritic gravel, with a rather high proportion of fines (A-2-4).

Relative density (compaction) achieved in production: five to six passes gave on average 96 - 99%. We have, however, quite often achieved relative densities of over 100%, and we can safely conclude that five to six
passes (fully ballasted) should suffice to achieve the required compaction of 93 - 94% Modified Proctor.

**Note:** It is our opinion that, as a rule of thumb, 95% Standard Proctor would be sufficient for most climatic conditions (100% for extremes). This could be the specified rate of compaction on labour-based gravel roads with this type of roller, until revised standards based on further research for intermediate equipment are available.

**Research**

Our comparison tests between the dead-weight Roller (1) and a one tonne pedestrian vibrating roller showed that the pedestrian vibrating roller achieved a higher density (by about 5%-10%) on this type of soil (a sandy lateritic soil with a high proportion of fines). However, the dead-weight roller has also met compaction rates well within the required margin. This project is not yet in a position to present compaction results/analyses obtained from research under controlled conditions. Our test results are obtained from production testing, and we are not sure to what extent traffic has influenced the results. However, the combined compaction effort of equipment, construction traffic and public traffic is what we should be measuring. Furthermore, compaction research has been carried out using similar types of roller at Kisii Training Centre by students from Switzerland and Kenya over the past two years. Their research reports are available from the ILO/ASIST Technical Enquiry Service in Nairobi.

**Roller (2) Double drum**

The second roller was designed based on the same basic compaction parameters but with rather different features as explained below:

**Function**

A *double drum* dead-weight roller to be pulled by a 60 - 70hp agricultural tractor. It has an increased width compared to Roller (1) to match the track width of the tractor. This is to reduce the number of parallel passes and make compaction of edges on dykes and embankments easier and safer when using a tractor-towed roller. For improved tractor traction, refer to the specifications of Roller (1) above.

**Overall design**

A pair of hollow steel rollers mounted in a frame, with a detachable towing bar (can be attached at front or rear), and with a steel bucket sitting on top of the frame.

**Transportation**

*Mode of transport*

Shipping weight is 1,600kg

Can be transported on an ASIST-promoted trailer partly filled with soil or on a specially built low-bed trailer of the type normally used for pedestrian vibrating-rollers, or on trucks. Attaching transport wheels is also an option.

**Operating weight**

Empty is 1,600kg; filled with water 2,700kg; fully ballasted 4,500kg.

**Volume of bucket**

Approximately 1m³.

**Drum dimensions:**

Double drum, diameter is 900mm, width of each drum is 850mm. Volume of one drum is 0.54m³, two drums give 1.08m³. Manufactured from 12mm

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8 ILO/ASIST Technical Enquiry Service, PO Box 60598, Nairobi, Kenya; Tel +254-2-560941; Fax +254-2-566234; E-mail: iloasist@iloasist.or.ke
thick steel plate. The drums can be ballasted with water, which gives an added weight of 1080kg.

**Compaction characteristics**

- Static linear load (empty) is 942kg/m
- Static linear load (filled with water) is 1576kg/m
- Static linear load fully ballasted is 2635kg/m.

**Manoeuvrability**

Turning radius improved by the use of two drums which can turn in opposite directions. Otherwise refer to Roller (1) above.

Working speed and transport speed are the same as for Roller (1) above. Stability greatly improved with increased width.

**Special features**

This roller has been designed with a number of special features, such as:

- A detachable drawbar which can be mounted at both ends (front and back) of the roller to be used in special circumstances such as when turning the roller on high embankments or on a dyke. This manoeuvre can be very difficult and dangerous. With this special feature, which adds very little to the total cost of the roller, the drawbar can be detached and mounted on the other end and the roller pulled in the reverse direction.
- A special feature of this roller is the provision for towing the roller off-set behind the tractor (as shown in Figure 1 below) thus allowing the rear wheel of the tractor to run safely 50cm inside the edge of, for example, an embankment. This arrangement still allows adequate compaction of the full width of the embankment. This feature would be even more advantageous if the tractor were fitted with a quick release hitch of the swivelling type.

![Fig. (1)](image)

Note: The system of off-setting tractor towed farm implements is common and well tested in the Agricultural Sector.

**Manufacturing and cost**

The roller was locally manufactured in Lusaka by the same mechanical engineering firm as for Roller (1). The cost was US$ 4,857 including development costs (but not including project staff costs).

The roller was delivered in October 1995 and has been in operation ever since. However, this roller developed a bearing problem and it was concluded that the bearing was under-dimensioned for the weight of the roller when fully ballasted. This fault was therefore corrected and the roller has not developed any further problems during the one-and-a-half years of its operation.
Performance (Mechanical)  
Durability has also been exemplary for this roller, as for Roller (1). However, Roller (1) must be considered more reliable and less likely to develop any mechanical problems than Roller (2), a design with double drums, longer axle and a rather more complicated bearing arrangement.

Performance indicators (Compaction achieved)  
Compaction density is slightly reduced compared to Roller (1) since the linear load is less, due to increased width of the roller, although the total weight is the same (about 4.5 tonnes). Obviously, the wider roller reduces the number of parallel passes required. However, the reduced compactive effect increases the number of passes required per line by at least one. This type of roller can be used for most types of material (except for clean sands, clays and oversize rock) and should therefore be suitable for gravelling operations. However, it is rather light for a static roller. Hence the moisture content should be carefully monitored and should be close to optimal to achieve maximum compaction.

Recommendation  
For those who intend to invest in dead-weight rollers and are looking for an appropriate design, we would recommend Roller (1), the single drum roller. However, it should be modified to include the drawbar arrangement of Roller (2), and eventually an increased drum width of 1,500mm. Although this will reduce compaction efficiency, 3 tonnes/m would be sufficient for most soils normally used for gravelling.

2.4.4 Future Plans
We are also in the process of designing the following equipment:

- A low-bed trailer for transporting dead-weight rollers, of the same type as often used for transporting of pedestrian vibrating rollers.
- Transport wheels attached to the dead-weight rollers which can be folded up when not in use, as shown in Figure (2) below.
- A roller of the pad foot type, also to be provided with a vibration mechanism. However, the vibration would not be produced by a small petrol or diesel engine mounted on the roller, but by using the tractor's PTO combined with a specially designed eccentric to provide the vibration.
- A specially designed semi-low-bed trailer with drop sides to be towed by a flatbed truck for the transport of tractors, rollers, water bowsers, trailers etc. to our demonstration sites some distance from Lusaka.

2.4.5 Summary
This article is not meant to be a contribution to the debate on whether we need compaction equipment or not. Nor do we want to disparage other methods since we do appreciate that adequate compaction can be obtained in many different
ways. The purpose of this article is to enlighten managers of rehabilitation contractor training programmes, and other labour-based practitioners, who have already decided that they need compaction equipment, about an alternative to the pedestrian vibrating-roller concept, in the shape of the dead-weight rollers described above.

As I mentioned earlier, we are not yet in a position to back up our development engineering work on appropriate equipment with complementary research since our tests were carried out on a production site. However, this should not give you sleepless nights, if you consider purchasing a dead-weight roller of the type described, since research carried out elsewhere, together with our production test results, provides sufficient guarantee of usefulness. This should be especially true for those of you who are engaged in training labour-based rehabilitation contractors. Such contractors typically have to produce about two kilometres of full rehabilitation of a feeder road per month, including 50% gravelling, in order to be able to repay the loan for equipment. Such loans may range from US$100,000 to US$150,000 over a four to five year period, and therefore a labour-based contractor is in dire need of equipment which is durable and which has low maintenance costs. To achieve a high rate of production, a roller should obviously be matched with an agricultural tractor of a make widely available in the country of operation, with spare parts in stock and trained mechanics locally available (and not just in the capital city).

Furthermore, as indicated by David Stiedl in his article on compaction equipment in ASIST Bulletin No. 3 of August 1994, the way specifications are written has to be adapted to this type of appropriate compaction equipment (although this also applies to the pedestrian vibrating roller). This means that the required compaction rate described in the literature as BS- or AASHTO- should also be described in a more empirical way as for example the number of passes required with a given linear load for a given type of soil. This type of specification has already been introduced in Kenya for labour-based applications, and is being introduced in Zambia. This means a change from performance specifications to method specifications and thus places more responsibility on the engineer. Relaxation of standards is an issue which shall have to be addressed by a successful contractor development programme, introducing intermediate technology equipment. Otherwise an emerging labour-based rehabilitation contractor will not be in a position to get his work approved and receive his monthly pay cheque when he is out of the protective environment of the project.

Seven dead-weight rollers based on the design of Roller (1) are being manufactured here in Lusaka, at a cost of US$ 3,259 per roller, for another ILO-managed labour-based project in the country. The only difference in design is that the width of the drum has been increased to 1,500mm. This is an ideal width for a five metre wide carriageway since it requires only four parallel bands with sufficient overlapping, at five passes per band, to be rolled. This roller can be transported on an ASIST-promoted trailer if a special low-bed trailer is not available.

All tractor-towed equipment used here in Zambia (apart from graders) is locally manufactured by mechanical engineering firms, thus providing the industry with an additional market. However, their existence is seriously threatened since they
receive fewer orders from the mines nowadays, and many contractors bring in their equipment duty free under the privileges of donor-funded programmes. This situation has had an adverse effect on our development efforts.

On the other hand, we have received very encouraging moral support in our development efforts from ILO/ASIST in Nairobi. We are also very glad that MART, through their Equipment Challenge, has initiated a design competition for appropriate equipment. One of the categories is tractor-towed dead-weight rollers, which clearly indicates the need for this type of equipment.

References


SCHEMATIC DRAWING IN SCALE APPROX. 1 : 30

ROLLER (1) SINGLE DRUM

ROLLER (2) DOUBLE DRUM

R = 500

R = 450
2.5 HAND TOOLS IN URBAN INFRASTRUCTURE PROJECT IN ADDIS ABABA

Tesfaye Kunbi, CARE Ethiopia, PO Box 4710, Addis Ababa, Ethiopia

Ethiopia is one of the least developed countries in the world. Constant urban migration to the capital of Addis Ababa over the past few years has resulted in an increasing number of urban residents living in extreme poverty. The Municipal Council of Addis Ababa estimates the current urban population at 3.0 million inhabitants. The majority of the city’s population reside in severe slum conditions, lacking adequate housing and the provision of basic services (e.g. potable water, sanitation, roads, health facilities, etc). The present day economy offers little employment opportunities, especially for unskilled labourers, and although food is readily available in the capital, most families in marginal communities experience food deficits due to the lack of adequate income required to meet their basic food requirements.

The Community Infrastructure Development/Urban-Food-For-Work Programme was developed by CARE Ethiopia in 1993 in an effort to address the needs of the urban poor, specifically the lack of primary infrastructure and excessive unemployment within marginal urban communities in Addis Ababa. The programme consists of a series of community based public work projects utilising a food-for-work model in order to provide improved basic services and generate short term employment opportunities for residents living in less economically favoured neighbourhoods within the city limits. The project undertakes the construction of access roads and the provision of sanitation facilities and water supply as these are main concerns of target groups. A socio-economic survey of the total households in a community, targeted as beneficiary of the project is undertaken. This is followed by a task force committee for site selection. This task force is mainly composed of representatives from the municipality of Addis Ababa, the Commission for Disaster Prevention and Preparedness and CARE. The committee having gone through the economic survey results, and visited the target communities, come up with lists of communities to be addressed by the project. The involvement of community members through labour-inputs is encouraged, alternatively a 5 - 10% financial contribution to the cost of construction materials is recommended. This is only to ensure that residents feel that they own the built infrastructure.

After having completed the basic documents like project design and cost estimation, budget allocation and sources, etc., the parties to be involved sign the agreements.

Project communities are encouraged to enrol the workforce from their own communities, however, if this is not possible, it is advised employ from neighbouring residential communities. The main actor besides CARE in the intervention is the Infrastructure Development Committee.
The committee takes over duties like management of project finance materials, and liaison of the project with government offices.

The construction materials required are provided by suppliers. Tenders for supply of construction materials to project sites are issued and evaluated by all parties involved in the project.

Workforces are paid based on the group outputs. There are fixed work targets set for every activity. Out of the group earnings skilled worker earn three rations, semi-skilled two rations and unskilled workers one ration day. One ration is equivalent to 3.5 kg of wheat and 175 gms of vegetable oil.

When project activities come to a close, the basic necessary tools are handed over to the committee to be used for maintenance purposes. A maintenance fund continues to be raised by community welfare associations and every household in the community. The project has built over 80kms of stone paved roads with an average width of 4.5m, 65 communal latrines to be used by 1,560 households, and eighth developed springs.

CARE is working along with local non-governmental organisations as partners with the aim of building their capacity. About 135 unskilled labourers have been promoted to skilled grade.

The urban food-for-work project is entirely funded by USAID. USAID allocates resources in the form of commodities (wheat and vegetable oil). Part of the vegetable oil is monetized to cover costs for construction materials, salaries and other expenses. The problems encountered are as follows.

To acquire a plot of land for an on-site sanitation scheme has become very difficult, owing to the government’s policy on land ownership. Land is government property in Ethiopia. Facilitation of land permits in government offices has become a big challenge to the project.

After having set up the maintenance schedule and method, the project phases out. It is observed that committee members neglect their duties and as a result maintenance responsibilities are not respected. The project life in a single communities is up to one year only. The project participants, numbering around 215 become unemployed again, after the project phases out. Only a small number (2%) has success in obtaining jobs on other related activities.

The projects being undertaken in these marginal communities involve the application of hand tools to a higher degree, owing to the fact that construction of the infrastructure works (access roads, communal latrines, spring developments, clinics, etc) are labour intensive. Only in exceptional cases are mechanical machinery, like concrete vibrators, rollers, water pumps, etc., applied.

The hand tools that are commonly used in the activities are shovels, pickaxes, crow bars, hammers, saws, wheelbarrows, etc. These tools are manufactured in local factories. Their life span ranges from one to two years. Some of these tools (especially shovels and wheelbarrows) are found not to be hard enough to stand up to the anticipated service conditions nor ductile enough not to crack.

Investigations at local manufacturing factories revealed good reasons behind every cracked die, every spelled cutting edge, and every broken chisel. Once in a while, it is true that tools failures are caused by defective steel. But hazardous
tool design, improper grinding and mechanical factors play a far greater role. Most frequent of all are failures due to faulty heat treatment.

It is highlighted that factors like good design, sound tool steel of the proper grade, correct heat treatment, proper grinding and proper application of the tools contribute to successful tool making. These fundamentals are like the links of a chain; a deficiency in any one of the elements, or links, leads to trouble. Each of the above mentioned factors must be given proper attention in order to achieve the best possible tool performance.

The cost of hand tools is about 3% of the total project, so a small investment in this element has a substantial impact on the productivity. Labour productivity is mainly influenced by effectiveness of organisation, supervision of labour-based activities, motivation of the workforce and the quality and efficiency of the tools used.

The quality of hand tools is entirely based on three factors: (a) efficiency (b) strength of the tool and (c) wear and durability. Investigations made in Kenya have shown that construction quality tools as compared with farm quality tools are more productive possibly because they were 25% lighter than the farm type. The main parameters involved are shape, size, weight and finish of the tool.

The strength of the farm tools was found to be inferior, mainly because of the lack of hardening of the steel. Using the correct grade of steel, medium-carbon, which allows hardening all the way throughout the tool (not just surface hardening) is important in achieving the strength to resist impact blows. The parameters are shape, size, material and heat treatment.

Another factor affecting labour productivity is the wear and damage of the cutting edges and working surfaces of the tools.

Workers benefit from having good quality hand tools in being able to complete work with less effort and in less time. They are also likely to be less fatigued and suffer fewer injuries such as blisters and muscles strains. There are, of course, significant benefits from reduced medical costs for the work force.

The following recommendations are made to promote the use of improved hand tools:

- create greater awareness of the importance of good quality hand tools to labour-based road works, particularly with procurement staff.
- present specifications in a more concise and readily accessible form. They also need to be backed up by simple tests that can be carried out on site to check that the tools comply with the specs. These consist of: a visual check on shape, dimensions and furnishings, as well as a blacksmith’s test to identify the steel used
- co-ordinate markets within countries so that demand is sufficient to encourage ready availability of better quality tools.

I will now make a few points about some of the hand tools that we are using.

### 2.5.1 Axes

The lighter the axe is, the easier it is to use and since accuracy is more important than weight for most cutting jobs, the weight should not exceed 1kg. Axes are the tools of specialists, and a compromise in quality and or design can be disastrous.
We have in certain parts of the city compensated for the use of own axes. Pre-delivery check and bending tests are essential to weed out sub-standard brands.

### 2.5.2 Crowbars

‘Fake’ crowbars made of reinforcement rods or other mild steel should not be considered for heavy construction work. Good quality (hexagonal) crowbars of a good steel grade are recommended.

### 2.5.3 Handrammers

Handramming has proved to be very difficult to control and is only recommended in connection with culvert laying or very small foundation works.

### 2.5.4 Shovels

The locally produced shovels proved totally inadequate with a blade that could easily be bent by hand. It is recommended that shovels be fitted with wooden handles of suitable length. The length of the handle for throwing or loading of trucks, should be at least 1.2m.

Although specifications are useful, it is sometimes not possible to carry out the necessary testing before delivery, and in such cases one has to rely on well-proven brand names/manufacturers.

The procurement of tools should be done well before the start of a project. This makes it necessary to provide separate (and faster) funding for the tools. This will also call for secure storage of the tools and it is recommended that a strict stores inventory system is enforced.
2.6 HAND TOOLS IN LABOUR-BASED WORKS: SOME NOTES FOR CONSIDERATION

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Summary

Lack of good quality and adequate supply of hand tools on labour-based work sites is a common problem that bedevils many labour-based construction projects. Hand tools constitute the driving force for productivity in labour-based works and are often the most critical items to consider when it comes to the progress of construction. Compared with the investment in capital equipment in capital-intensive works, the capital outlay for investment in hand tools in labour-based works represents only a small proportion of the total project cost. Ironically, however, it is in hand tools that many labour-based practitioners and contractors hardly direct any investments because the supply of tools and capital provision for their supply are not perceived as important issues. In this paper, issues pertaining to hand tools in regard to quality, supply and management and the importance of hand tools in labour-based works in general are discussed.

2.6.1 Introduction

In labour-based construction, hand tools are the major items employed by labour for productivity. Whereas it is possible to construct roads using labour and hand tools without equipment, it does not appear possible to do so with labour and equipment without hand tools (Makoriwa, 1993). In effect, hand tools represent the driving force for productivity in labour-based construction. A unique aspect of labour-based construction is that compared to the investment in capital equipment for capital-intensive works, the capital outlay for investment in hand tools for labour-based works represents only a small proportion of the total project cost.

Fortunately for labour-based works, hand tools do not usually pose procurement problems because unlike capital equipment which for developing countries must be imported specifically for the construction industry and under special order, hand tools employed on labour-based works are simple tools developed primarily for the agricultural sector and which for many developing countries may be locally purchased. In some developing countries with an intermediate technology base, hand tools may be easily manufactured by local artisans. Although hand tools are crucial to the successful execution of labour-based works, many practitioners and contractors associated with labour-based construction technology do not appear to give hand tools the attention that they deserve.

The progress of labour-based projects can be slowed down if construction problems associated with hand tools are persistently ignored or left unresolved. In a study of the performance of selected labour-based contractors in Ghana, some of the major factors observed to hamper progress of construction at various
contractor sites related to hand tools. On some construction sites, it was common to find tools questionable quality, tools with broken handles or tools in a completely worn-out state being used. The most serious tool problem requiring urgent attention related to supply. It was not uncommon to find workers chasing after tools at the beginning of the workday.

On one contractor site, inadequate supply of tools compelled workers to supplement tools on site with hand tools brought from their homes. Obviously, in situations where there is a lack of such goodwill and co-operation on the part of workers, worker output could be very low as a good proportion of workers spend a significant proportion of the available man-hours idling or waiting for a given type of hand tool to become available. Even on some construction sites where most of the tools were found in a satisfactory state or were available in sufficient quantities, there was no evidence of a proper set-up for effective tool management. Such situations could easily give rise to problems such as tool loss and pilfering which would call for frequent replacement and replenishment of stock. In a typical case, for example, a contractor kept his tools in a private kitchen in one of the villages along the construction route. This allowed pilfering of tools to go unnoticed and unchecked as workers who went for the tools at the beginning of the day were not accountable to anyone for their return at the end of the day. This seemingly isolated case epitomises the general lack of appreciation of the importance and relevance of hand tools in labour-based works and the need to take the issue of hand tools very seriously.

Despite the direct and obvious link between hand tools and productivity, many labour-based practitioners have failed to direct the needed investments to hand tools. In this paper, the issue of hand tools is discussed. The focus is on tool quality and quantity. Some titbits on general tool management are presented to help labour-based practitioners practise effective and efficient tool management for their works.

2.6.2 Tool Quality and Supply

Quality and quantity are two attributes that rarely go together in many real life situations, but when it comes to hand tools in labour-based works, it is important and necessary that tools of the right quality be in the right quantities at the right time. Tool condition is usually placed in three quality rating categories, namely; excellent (T3), satisfactory but needing some attention for improvement (T2), and unsatisfactory or defective needing replacement (T1). An indication of the tool supply situation can be obtained through the tool availability ratio defined as the ratio of the number of tools available for a given task to the number of labourers assigned to that task. The ratio in a sense measures the probability that a worker assigned to a particular task will have the necessary tool to work with as and when required. Obviously, the tool supply situation in respect of a given tool for a given activity is satisfactory if the tool ratio is at least unity. In gang work with several sub-activities, such as for example, excavation and loading of gravel, which requires several different hand tools to execute, the tool ratio concept must be interpreted to mean the availability of all the needed tools for all the sub-activities such that each and every worker within the gang or group will have a tool to work with as and when needed.
Table 1 provides an overview of the general tool situation on a number of labour-based construction sites in Ghana. A tool situation worse than that provided by the table is unlikely to result in productive output on site and may require intervention on the part of management to raise productivity levels. In the case of tool quality, simple interventions like smoothening of handles and sharpening of tool heads may be all that is needed to restore tool quality and improve worker efficiency and output. In many cases, this action is seldom carried out allowing tool quality to deteriorate to unacceptably poor levels.

Neglect of tool quality and stock replenishment are likely to result in the following major costs to both the worker and his employer (labour-based contractor):

- increased worker fatigue
- low worker efficiency
- low productivity
- poor quality work
- reduced worker earnings
- increased worker time input
- increased idle time
- disruption of work schedule
- reduced flexibility associated with piece- and task-work systems in accommodating other worker obligations and interests such as farming activities.
- delay in project completion.

In the case of loss of the flexibility associated with the task- and piecework systems, labour-based activities in areas with predominantly agricultural activities could lose out to agricultural activities for labour during periods of intense and heightened farming activities. Experience shows that labour in such areas is only willing to accommodate labour-based activities alongside their farming commitments in so far as the system of work contract between the worker and the contractor in the labour-based works pays on the basis of “finish-and-go” rather than “by-day”. If due to poor quality and non-availability of the right tools at the time when they are needed workers will have to spend a greater part of the day on their piecework or taskwork to the detriment of their farming commitments, or if at the end of the work they feel fatigued and exhausted, they are unlikely to consider their participation in the labour-based works as of any benefit to either their short- or long-term interests.
Table 1. A typical tool situation on labour-based site in Ghana

<table>
<thead>
<tr>
<th>Activity</th>
<th>Recommended tools</th>
<th>Tools in use</th>
<th>R&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Tool condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bush clearing</td>
<td>Cutlass, sharpening stone</td>
<td>Cutlass</td>
<td>1</td>
<td>T2</td>
</tr>
<tr>
<td>Grubbing</td>
<td>Hoe, cutlass, spade, bolster rake, headpan, pickaxe/mattock</td>
<td>Hoe</td>
<td>1</td>
<td>T2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Headpan</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rake</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>Filling of gullies, depressions, etc.</td>
<td>Shovels, hand rammer, wheelbarrow, mattock/pickaxe</td>
<td>Mattock</td>
<td>0.93</td>
<td>T2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spade</td>
<td>0.93</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Headpan</td>
<td>0.56</td>
<td></td>
</tr>
<tr>
<td>Cut widening</td>
<td>Shovel, spade, pickaxe/mattock</td>
<td>Mattock, Spade/shovel</td>
<td>1</td>
<td>T2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spade/shovel</td>
<td>0.81</td>
<td></td>
</tr>
<tr>
<td>Ditching/Sloping</td>
<td>Pickaxe/mattock, ditch/slope template, spade, string</td>
<td>Mattock</td>
<td>1</td>
<td>T2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spade/shovel</td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td>Camber formation</td>
<td>Spade, pickaxe/mattock, rake, pegs, watering can, sledge hammer, camber board,</td>
<td>Spade</td>
<td>1</td>
<td>T2</td>
</tr>
<tr>
<td></td>
<td>wheelbarrow, spirit level</td>
<td>Rake</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Gravel excavation</td>
<td>Shovel, pickaxe/mattock, fork hoes, ranging poles</td>
<td>Mattock/pickaxe, Spade/shovel</td>
<td>1</td>
<td>T2</td>
</tr>
<tr>
<td>L-H-O of gravel</td>
<td>Shovel</td>
<td>Shovel</td>
<td>0.93</td>
<td>T2</td>
</tr>
<tr>
<td>Gravel spreading</td>
<td>Spade, watering can, rakes, pegs, strings, spirit level, hand rammer, camber board,</td>
<td>Spade/shovel</td>
<td>0.81</td>
<td>T2</td>
</tr>
<tr>
<td></td>
<td>wheelbarrow</td>
<td>Rake</td>
<td>0.53</td>
<td></td>
</tr>
</tbody>
</table>

R<sup>1</sup>=Tool ratio-defined as the number of tools available for task to number of workers assigned on task. R<1 indicates insufficient quantity of tools.

T1: Both tool handle and tool head are worn out. Replacement required.

T2: Condition of tool is such that sharpening of head or smoothening of handle will greatly improve its efficiency.

T3: Excellent condition, virtually no defect visible.
2.6.3 Tool Management

Labour-based works may be executed much more efficiently and successfully if proper and effective tool management is practised. The essence of tool management is to ensure that the right type of tool in the right condition is available at the right time for executing a given activity. Improper tool management may create supply problems and impede the speed of the construction. In some cases, it may require additional investment in tools as the available stock is depleted through theft from lack of proper control and care.

For proper tool management, it may be necessary to assign the responsibility of hand tools for site activities to a supervisor or personnel who may be designated the tools manager. The tools manager must be charged with the following responsibilities:

- keeping a daily record of tools issued out for site activities and returned at the end of the work day
- keeping a periodic inventory of tools
- drawing up a programme for the quantity and type of tools required at all stages of construction
- advising on the storage arrangements to protect wooden tool handles from fungi and termite attack
- providing a periodic update of the state of tools regarding both quality and quantity for the attention of the contractor
- monitoring the rate of tool wear, breakage, and loss
- establishing preferences of the local labour in the use of the different types of hand tools
- identifying and providing a list of changes needed to be made in future orders of hand tools regarding, for example, brand and type
- where tool replenishment or replacement is anticipated he must pass the information on to the contractor for purchases to be carried out ahead of time of anticipated need
- drawing up a programme for periodic restoration of or improvement in the quality of tools through sharpening of tool head and smoothening of handles

Because labour-based activities are organised under supervisors and gang leaders, it is considered much more efficient to deal with supervisors and/or gang leaders rather than the individual workers regarding matters of hand tools for the daily activities. Supervisors or their gang leaders must be responsible for signing for tools for co-workers within their gang or under their supervision and ensuring their return to the tool manager at the end of each work day. The incidence of tool theft can be minimised considerably if the cost of a missing tool is charged against the supervisor or the workers within a gang responsible for the missing tool. This policy must be made clear to all workers by the tool manager, or the contractor or his representative on site to ensure full co-operation of all workers in controlling tool loss and theft. There must be a buffer stock of tools so that damaged tools can be replaced immediately when necessary and/or losses catered for to avoid disruption of certain site activities.
Tool managers must not deal directly with individual workers unless a worker has some useful information to provide for the general attention of the tool manager in regard, for example, to the difficulty of use of a given brand and type of tool, which information may be useful for guiding future investments in tools.

2.6.4 Why the Low Investments in Hand Tools?

Non-availability of good quality tools on the local market, incompetent purchasing officers and importation restrictions are some of the reasons put forward to explain the low investment in hand tools or the deplorable state of hand tools on many labour-based construction sites (Makoriwa, 1993). Even though some of these reasons may be tenable in certain cases, in most cases, the main reason for the hand tool situation seems to be the fact that the supply of tools and capital provision for their supply are not perceived as important issues (Howe, 1988). This appears to explain why, for example, some years after embracing the labour-based technology, a number of countries with the potential to manufacture hand tools comparable in quality to those from overseas sources have not formulated any coherent strategy for the manufacture of hand tools locally and continue to depend on overseas sources for supply.

There appears to be another dimension to the problem of low investment in hand tools; it is thought that perhaps the types of work contracts practised in labour-based works (most of which are task- or piece-rate systems) in themselves do not provide adequate incentive for the employer/contractor to invest adequately in hand tools. After all, for such types of contracts, the onus of getting the job accomplished in order to earn the associated benefits (wage) is on the labourer. It is very easy in such cases for the contractor to shirk his moral responsibility of facilitating the execution of the contract (in this case a taskwork or piecework) for the worker by ensuring that the right set of tools is made available to the worker at the right time.

According to Howe (1988), the general problem of low investments in hand tools may be addressed by creating a greater awareness at all levels of how crucial good quality tools in sufficient quantities are to road improvement and maintenance by the labour-based technology. An effective way to do this is to organise national workshops on the subject periodically. Whatever the case, it must be clear to all labour-based contractors and practitioners that there are no alternatives to investments in hand tools in the labour-based technology and that such investments serve the interests of such stakeholders better.

2.6.5 Conclusions

This paper looked at the investment in hand tools by labour-based contractors/practitioners. It noted and discussed the effects of tool quality and quantity on productivity and the general progress of labour-based works. Basic aspects of tool management were presented for the consideration of labour-based contractors and practitioners. The poor investments in hand tools characterising the labour-based industry are attributed to the fact that the supply of tools and capital provision for their supply are not perceived as important issues by stakeholders in the industry. It is also thought that because the type of work contract practised in labour-based works is mostly task- or piece-rate systems, there is very little incentive for the contractor to provide the necessary tools to
facilitate the execution of the contracted activities by the labour-based worker. To address these problems, it is thought that a greater awareness needs to be created of the importance of investments in hand tools in labour-based works through local and national workshops on the matter. Finally, it is stressed to all stakeholders in the industry that there are no alternatives to hand tools in labour-based technology.

References

2.7 LESSONS FROM THE COMPACTION OF SOME LOCAL SOILS FOR FEEDER ROAD CONSTRUCTION IN GHANA

Ampadu, S., K. (Ph.D., SM.GhIE), Civil Engineering Dept., School of Engineering, University of Science and Technology, Kumasi-Ghana.

Summary
A comparative technical quality study of roads built with labour-based and conventional equipment-intensive technologies in Ghana, showed that on the average the level of compaction achieved on labour-based projects were 10% lower than those achieved on equipment-intensive projects. Using data from this and other studies, this paper discusses some of the factors which might account for the lower levels of compaction achieved on labour-based roads.

2.7.1 Introduction
In Ghana, the most common types of soils used as subgrade and base material for highway pavement construction and as the wearing course on unsurfaced roads, are the soils formed from the decomposition of rocks known as granites and phyllites. In almost all the situations in which these soils are used in road construction, it becomes necessary to compact the material to very high levels of compaction. The normal practice is to attempt to attain the Modified AASHTO\(^9\) level of compaction. The specification adopted by the Ministry of Road and Transport in Ghana requires that subgrades and bases be compacted to a minimum of 95% and 98% respectively of the maximum dry density (MDD) obtained with the Modified AASHTO standard. The rationale behind this is that at the MDD, strength is known to be high and compressibility low. However, this general observation has not been found to be true for tropical soils, some of which are known to be very unstable.

Over the past few years, the ILO has assisted the Civil Engineering Department of UST in building its capacity in the area of labour-based road engineering. Part of the programme includes comparative studies into the technical quality of roads being built with conventional capital-intensive technology and those being built with labour-based technology. This paper looks at the issues that the studies have raised concerning some of the technical factors that affect the compaction of these local soils.

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\(^9\) The Modified AASHTO specification fills a 2.105 x10\(^{-3}\) m\(^3\) mould in five layers, subjecting each layer to 55 blows of a 4.54 kg rammer dropping through a 0.457m height
2.7.2 Brief Description of Methodology

A number of feeder roads in the country constructed using conventional equipment-intensive method and those using labour-based methods were selected for the technical quality studies. On each road, up to three newly gravelled sections were selected and on each section, the level of compaction achieved was determined using the sand replacement method. Other tests included the determination of the thickness of the gravel layer and the measurement of the camber of the road section. In addition, samples of material were recovered from the gravel pits and subjected to routine laboratory identification and classification tests. The laboratory compaction characteristics of each sample were also determined. In this paper, only the results of the compaction measurements are presented and discussed briefly. The details of the study and the results of other measurements are reported elsewhere.

2.7.3 Discussion of Compaction Results

2.7.3.1 The level of compaction achieved

The levels of compaction achieved on eight capital-intensive and on six labour-based projects are shown in Table 1. It can be seen that even though neither the equipment-intensive nor labour-based projects achieved the minimum DFR specification of 98%, the field densities achieved on the labour-based roads are on the average 10% lower than those achieved on the equipment-intensive roads.

Table 1. Summary of field and laboratory results on compaction of feeder roads

<table>
<thead>
<tr>
<th></th>
<th>Equipment-Intensive Projects</th>
<th>Labour-based Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OMC(1) MDD(1) Field Dry Density (2) Level of Compaction</td>
<td>OMC MDD Field Dry Density Level of Compaction</td>
</tr>
<tr>
<td>(%) (Mg/m³) (%) (%)</td>
<td>(%) (Mg/m³) (%) (%)</td>
<td>(%) (Mg/m³) (%) (%)</td>
</tr>
<tr>
<td>9.12 2.11 1.94 92</td>
<td>11.01 2.177 1.756 81</td>
<td></td>
</tr>
<tr>
<td>9.50 2.134 2.030 95</td>
<td>11.00 2.115 1.769 84</td>
<td></td>
</tr>
<tr>
<td>9.99 2.083 1.96 94</td>
<td>6.77 2.177 1.777 82</td>
<td></td>
</tr>
<tr>
<td>13.50 2.060 1.98 96</td>
<td>11.16 2.154 1.867 87</td>
<td></td>
</tr>
<tr>
<td>9.30 2.13 2.02 95</td>
<td>7.05 2.294 2.015 88</td>
<td></td>
</tr>
<tr>
<td>11.00 2.15 2.09 95</td>
<td>10.15 2.229 1.739 75</td>
<td></td>
</tr>
<tr>
<td>11.00 2.012 1.895 94</td>
<td>Average 2.229 1.739 75</td>
<td></td>
</tr>
<tr>
<td>9.20 2.241 1.870 83</td>
<td>Average 93</td>
<td></td>
</tr>
</tbody>
</table>

(1) MDD and OMC are based on the Modified AASHTO specification using 55 blows per layer
(2) Field density was measured by the sand-replacement method.

Two issues that arise from these results are:

a) the appropriateness of the compaction plant being used for labour-based compaction in Ghana, and
b) the effectiveness of moisture conditioning during compaction, which is related to the method of compaction being used in the field.

2.7.3.2 The appropriateness of labour-based compaction plant

The compaction plant

The method of compaction in the field is usually described by the mechanical plant used. Compaction may be achieved by static pressure, by impact loading, by vibration, or by a combination of these. Table 2 is a summary of the types of plant generally available for compaction.

Table 2: Summary of types of common compacting plant

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Type</th>
<th>Description</th>
<th>Suitable for</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rollers</td>
<td>Static smooth-wheel roller</td>
<td>Employs two or more smooth metal rollers. Provides compactive effort primarily through static weight</td>
<td>All soil types except wet clays and uniform sands.</td>
</tr>
<tr>
<td></td>
<td>Static pneumatic roller</td>
<td>Consists of a number of highly inflated rubber tyres. Varies from small rollers to large and heavy ones. Provides a smooth finish to surface.</td>
<td>Clayey and silty soils</td>
</tr>
<tr>
<td></td>
<td>Sheep foot roller</td>
<td>Consist of drum with metal projection. Imparts high compaction pressures and. compacts by kneading action.</td>
<td>Fine grained soils (clays and silts)</td>
</tr>
<tr>
<td></td>
<td>Vibratory rollers</td>
<td>Compacts by vibratory and pressure action</td>
<td>Granular soils</td>
</tr>
<tr>
<td>Tamper</td>
<td></td>
<td>Compacts by vertical blows</td>
<td>Areas inaccessible to rollers.</td>
</tr>
</tbody>
</table>

Generally, for compaction of feeder roads, vibratory rollers are used. Vibratory rollers send pressure waves through the soil at a wide range of frequencies depending on the size of the plant. In normal soils, compaction is achieved by a combination of vibration and pressure. Thus, in addition to the dynamic pressure, the static weight of the roller is also an important factor in its performance. Vibratory compactors range from a 135 kg vibrating plate to 13,000 kg towed vibratory roller and may be used for compacting a wide range of material from sands and gravels to boulders.

The standard compaction plant which labour-based contractors use in Ghana is the “Bomag 65S” pedestrian vibratory roller with an operating weight of 600 kg. This compaction plant gives a static linear load of 4.6 kg/cm and operates at a frequency of 58 Hz. On equipment-intensive projects, a range of compaction plant including 10,000 kg (10-tonne) rollers was observed on site. For a 10 tonne SAKAI SV100 vibratory compaction plant, the equivalent static linear load is of the order of 24 kg/cm. It can be seen that the capacity of labour-based compaction plant may be only a fifth in terms of static linear load or only 6% in terms of the gross static weight of the compaction plant being used on equipment-intensive projects.

10 Recently new labour-based contractors are being equipped with the heavier “Bomag 90S” with an operating weight of 1,300 kg which gives a static linear load of 7.2 kg/cm and operates at 55 Hz.
intensive projects. The adequacy of such low capacity labour-based compaction plant for compacting local soils, needs to be further evaluated.

2.7.4 Effect of Compactive Effort on Level of Compaction

In order to throw more light on the effect of compactive effort on the compaction characteristics of local soils, the laboratory compaction characteristics of the gravel material obtained using 10 blows, 25 blows and 55 blows of the Modified AASHTO specification were determined. In addition to these tests, the laboratory compaction characteristics using the Standard Proctor specification\(^{11}\) was also determined. The results of two such tests are shown in Figs 1(a) and 1(b). The index properties and the AASHTO classification of the material are also shown in the figures. In Fig. 1(b), only the curves for the modified AASHTO at 55 blows and the Proctor Standard are available. The figures show the well known results of increasing MDD (with a corresponding decrease in the OMC) as the number of blows increases. It may be noted, however, that the increase in MDD from the Proctor Standard to the Modified AASHTO (55 blows) standard for test LB-BA-TT is larger than that for LB-WR-DL1.

Figure 1(a): Effect of compactive effort on A-2-6(2) Material
In order to have a common basis for comparing the compactive effort from different standards, the concept of specific energy was applied. The specific energy is the energy applied to the soil per unit volume during the compaction process. The values of the levels of compaction using the MDD value at a specific energy of 1,727 kNm/m$^3$ as a base are shown plotted against the input specific energy in Figure 3. The figure clearly shows that the effect of specific energy on the level of compaction depends on the type of soil. Whereas the material classified as A-2-6(2) in the AASHTO system gave a 96% level of compaction for a specific energy of 542 kNm/m$^3$, the same specific energy gave a level of compaction of only 80% for a A-7-5(5) material.

Table 2: Specific Energy for various compaction specifications

<table>
<thead>
<tr>
<th>Compaction Specification</th>
<th>Specific Energy, E (kNm/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified AASHTO using 55 blows/layer</td>
<td>1727</td>
</tr>
<tr>
<td>Modified AASHTO using 25 blows/layer</td>
<td>785</td>
</tr>
<tr>
<td>Modified AASHTO using 10 blows/layer</td>
<td>314</td>
</tr>
<tr>
<td>Standard Proctor using 25 blows/layer</td>
<td>542</td>
</tr>
</tbody>
</table>

Specific Energy, $E = \frac{NnWh}{V}$ where $N =$ number of blows on each layer of soil in the mould; $n =$ the number of layers required to fill the mould, $W =$ the weight of the tamper; $h =$ the height from which the rammer falls and $V =$ the total volume of the mould.
In the field, when rollers are used the specific energy depends on the pressure and the contact area between the roller and the soil, the thickness of the layers being compacted and the number of passes. This laboratory result suggests that in general for good quality road base material, relatively high levels of compaction can be achieved with relatively lower levels of energy.

### 2.7.5 Moisture Conditioning During Compaction

The MDD and the corresponding OMC values in Table 2 are shown plotted in Figure 3. It may be seen that the OMC values for the material used on the road varied between 6% and 14%. However, the bulk of the data fell between 9 and 11%. This suggests that in order to achieve high levels of compaction, the water content of the material must be controlled within 9-11%. Studies done in Ghana (GHA, 1970) showed that whereas most of the OMC values fell between the relatively narrow range of 6-12% confirming the results of our studies, the *in situ* moisture content of lateritic gravel in the moist sub humid climatic zone ranged from as low as 2% to 28%. This suggests that it is not likely that the *in situ* water content would fall within the desired 2% of the OMC. From considerations of strength reduction on soaking, it has been suggested elsewhere (Gidigasu, 1991) that the concept of OMC and MDD be abandoned as a necessary placement condition in favour of placing at least sub-grade layer at a stable *in situ* moisture content.
In practice, however, when the *in situ* moisture content of the gravel material is low, it may be necessary to add water to the material before compacting. On the other hand, where the material is wetter than the optimum, it may be necessary to reduce the moisture content by aeration. However, it appears the direction of water content change has some effect on the compaction characteristics. Figure 3 is a summary of the results of a study to investigate the effect of direction of water content change on the compaction characteristics of residual soils derived from granites and phyllite (Ampadu, 1997). The results suggest that the effect of the direction of water content change on the compaction characteristics depends on the type of material. For materials derived from granites, the effect on the MDD is negligible, but for those derived from phyllites, the change can be as high as 4% of MDD.
2.7.6 Effect of Compaction on Particle Breakage

Figures 5(a) and 5(b) show the effect of laboratory compaction on the grading curves for granites and phyllites respectively. The figures are for re-used samples but a similar trend was observed even when fresh samples were used. The figures show clearly that compaction leads to particle breakage for both granites and phyllites, but the effect is much larger on phyllites than on granites.

Figure 5a: Effect of compaction on grading of decomposed granite

The issue of whether higher or lower densities would be obtained in a particular compaction method depends on whether the breakdown of particles during compaction leads to an improvement or a deterioration of the grading. These
results suggest that high compactive pressure may lead to particle breakage, which can affect not only the level of compaction, but also other properties of the pavement as well.

Fig. 5b: Effect of compaction on grading of decomposed phyllites

![Graph showing the effect of compaction on grading of decomposed phyllites.](image)

### 2.7.7 Field Compaction Control

Finally, the results of a field compaction control for the subgrade in decomposed phyllites for a construction project are shown in Fig. 6. The compaction plant was a 10-ton HAMM smooth drum vibratory roller and several passes were applied to the imported material. The laboratory compaction curves obtained by the Modified AASHTO for two samples of the material are superimposed. This figure serves to illustrate some of the problems encountered in the compaction of local soils.
Fig. 6: Typical compaction control in decomposed phyllites

a) With the possible exception of one point, all the field dry density points fell below the laboratory compaction curve even for water contents close to the optimum (for Sample No. 2).

b) Except for one point, the placing water content was higher than the optimum moisture content for the particular material illustrating the importance of moisture conditioning.

c) Despite the high capacity compaction plant utilised (10 ton vibratory roller) the levels of compaction achieved ranged from a low 86% to 95% of modified AASHTO

d) The compaction characteristics of the material from the gravel pit changed with depth as evidenced by the different compaction curves for Samples No. 1 and No. 2. Such changes have been observed over profiles of phyllites.

It is suggested that the lower levels of compaction achieved on labour-based roads in Ghana may be attributed partly to the rather low static weight of compaction plant being used. On the other hand, the availability of high capacity compaction plant does not necessarily guarantee a high level of compaction.

2.7.8 Conclusion

From the results of our studies into the levels of compaction achieved on equipment-intensive and on labour-based projects on local soils, the following preliminary conclusions may be drawn:

a) The 600-kg BOMAG 65S currently being used on labour-based projects appears too light to achieve the required levels of compaction under field conditions. There is a need for further study into the optimum capacity of compaction plant for compacting gravel on labour-based roads.
b) The use of high capacity plant by itself does not guarantee a high level of compaction. Moisture conditioning during compaction of local soils is an important factor.

c) There is the possibility of particle breakage arising from high pressures and this can lead to difficulties with achieving high levels of compaction. This should be taken into account in selection of plant for compaction.

References


Gidigasu, M. D. 1991 Characterization and use of tropical gravels for pavement construction in West Africa


2.8 CONSIDERATIONS FOR THE DESIGN OF TOOLS FOR LABOUR-ENHANCED ROAD CONSTRUCTION AND MAINTENANCE

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Summary

Many years ago, all roads were built by hand using simple tools. The Incas of South America, the agricultural communities of the South Western USA, the Romans of Europe - all these are known as great road builders. The passage of centuries brought little in the way of improvements. MacAdam in Canada invented the split stone topping that was the forerunner of today’s paved “black-tops” but otherwise little has occurred to profoundly change how roads are built. Today’s roads are better in that they have stronger bases, higher load ratings and are smoother and flatter. When one talks of labour-based or labour-enhanced road construction, it is therefore very inviting to think of using the tools and methods of days gone by.

An inherent danger in this is the temptation to ignore advances in soil sciences, stabilisers and particularly materials for making tools and carts. Modern labour-based road construction and maintenance must use up-to-date materials, tools and models of organisation.

Modern labour organisation is very different from the methods of the past. Road construction is inherently management-intensive if it is labour-based - a little realised fact. This paper takes a brief look at the macro picture of tool design, taking into consideration the limitations of human and animal bodies, the nature of the work being performed, and some modern materials that can contribute to the making of more efficient tools.

Lowest-first-cost technologies are frequently given as examples of “appropriate technology”, not because they are inherently appropriate, but because they fit a romantic notion that a professional job can be done with amateurish tools and techniques. Any technology that is not an appropriate technology is, by definition, an inappropriate technology. Modern, labour-enhancing methods of road construction and maintenance require the application of effective mathematical modelling, tool fabrication and management systems. Compared with the amount of funds spent on researching and promoting heavy equipment, the option that offers the most jobs and social benefits - the labour-based model - has been virtually abandoned. In the re-emerging rural economies of the less developed countries, it is imperative that this situation be reversed.

Let me begin by noting that the giving of advice on how to design road making tools is a difficult task to undertake because the problems are so diverse that the uttering of one idea merely provokes the surfacing of another three. I can only
hope to give you some basic idea, some simple mental tools, that you can use to embark on your own inventive pursuits.

2.8.1 Working with Nature

The nature of labour-based activity is governed by the human body, its abilities, weaknesses, durability and willingness. The nature of road construction is governed by a need to create something quite unnatural: long strips of smooth and level ground. The nature of tool design is governed by the tasks at hand, the materials available to make tools, the skills available to shape those materials and the type of labour to be employed.

2.8.1.1 Nature of the human body

We start with the human worker's body. The study of its movement, conditions and efficiency is called ergonomics. Basically, this means the study of human work. Work can be measured in “ergs”. Road construction and maintenance is about the hardest thing people are willing to engage in other than perhaps open-pit mining as it is done in Brazil. To be cost-effective, in other words to be financially viable, the road worker must be made as efficient as possible and to do that, he requires good tools and techniques. It is a fact that there are very few good tools available for road workers and the techniques are only now being rediscovered, having been lost for 50 or more years in most parts of the world. It is in old, out-of-print books that you can find some of the most useful information on the application of human energy to various tasks. Where, for example, would you find out how much soil should be loaded onto a shovel at a time in order to maximise the efficiency of someone loading a cart? The answer is 10 kg. A number of other questions spring to mind. Are modern shovels sized to hold this amount? How high should the cart be? What is the optimum lift-over height for a soil- transporter? Are modern vehicles and carts designed with human labour in mind? Well, the answer to the last question is a loud “No!” Modern trucks and carts are designed for the road they travel on, not the people who build them. An existing road has bumps of a certain size, which defines the suspension travel, they have a certain load capacity, which defines the wheel size and number, and that combination defines the height of the side of the body. Workers loading soil or gravel must cope with a design optimised for something other than ergonomics. Design of “transportation as if workers mattered” has hardly even begun.

One of the most important elements of manual labour is appropriate rest periods. Research has shown that the amount of steady work a man can perform, even under enthusiastic conditions, can be more than tripled if proper rest periods are integrated into the daily routine. This is a very important part of labour-enhanced methods becoming economically competitive.

As we are discussing human-based road construction, references to animal draught power are included as an element because it is common to find animals such as donkeys and oxen working with people on civil works projects. The study of animal power is still current and a lot of material (and skill) is available for

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12Poncet, Morin, Rankine, et al, see Appendix 1
effectively using them on construction projects of all sizes. In conclusion, labour-based road construction involves the effective use of men, women and animals.

2.8.1.2 Nature of road construction

The nature of road construction is such that it involves the movement of large amounts of heavy material. It also involves the never-ending task of maintenance, repair and upgrading. The variety of climates, terrain and load capacity is such that it is impossible to speak of a “typical” road when discussing tool design in general. The simplest descriptions of road construction will point the practitioner in the right direction and then they are on their own.

Road construction requires the following tasks to be accomplished:

Digging, transporting, mixing, spreading, compacting, levelling, contouring, water transporting, stone splitting, rock crushing and sand sieving. I also introduce the task of “pre-compacting” because when working with hand tools, it is faster to use different tools for pre-compaction and final compaction.

These tasks are to be accomplished on a variety of slopes, using different raw materials, finishing to various standards and using available labourers and animals. It is important for the experienced contractor to be able to match the correct tool to the selected labourer for the task at hand. With road construction, almost nothing is impossible. Remember that the recently completed Karakoram Pass - hundreds of miles of road hacked through the Himalayas from Pakistan into western China - was almost entirely built by hand. Nothing we do will ever come close to that achievement.

2.8.1.3 Nature of tool design

The designer of tools must effectively match four factors: the tasks at hand, the materials at hand, the tool-making skills available and the type and skill level of the labourers. Before going to design elements, here are listed some of the tasks and the tools frequently used. Some of the tools are unavailable in our respective regions and some have been forgotten.
Digging (including removing topsoil)

Loosening     Pickaxe/straight crowbar/fork/ripper
Lifting       Spade/shovel/bucket/dragline
Breaking      Sledge hammer/spade/shovel/tamper/roller

**Transporting**     Chariot/cart/wagon/truck/wheelbarrow/basket/slurry

**Mixing**     Hoe/shovel/spade/manual mixer/trough/dragged log/plough/cultivator

**Spreading**   Rake/rake-like spreader/cart with trap door/hoses/dragged log/grader

**Pre-Compacting**     Flat bottomed sled/compact
eroller/tamper/roller/jumping jack

**Compacting**       Tamper/jumping jack

**Levelling**       Toothed beam/profile, spade and tamper/grader

**Contouring**       Profile, spade and tamper/grader

**Sealing**         Watering cans/push carts/brooms/mops/hoses/spade and tamper

**Water**
- **Transport**     Chariot/bowser/cart with container/bucket/hose/ wheelbarrow/truck
- **Storing**       Tank/bag/channel/pond/dam/drum/bowser/ swimming pool
- **Spraying**      Watering can/cart with drilled pipe/hose
- **Treating**      Dosing water with surfactants (detergent)
- **Stone splitting**     Sledge/shaped sledge/hammer/chisel

**Rocks**
- **Crushing**      Sledge/shaped sledge/hammer/anvil/chisel/rock crusher
- **Sorting**       Screen/sieve/rake
- **Digging**       Pick/straight crowbar

**Sand sieving**    Screen/sieve
2.8.2 Basic Design Criteria

2.8.2.1 Available power - Humans

A well fed man can work with a continuous output of about 100 watts and a woman, about 80 watts. Short bursts of energy can reach three times that. Carefully designed tasks that require bursts of energy requiring 300 watts can be done for many hours if proper rest periods are included. As can be seen from Appendices 1 and 2, a man can accomplish about five times as much work turning the crank of a capstan as he can shovelling soil up 1.5 metres into a truck. In other words, what the person is doing and with which tool, greatly influences how much nett work can be accomplished. For example, a person walking up and down a ladder all day does a great deal of work (about 95 watts continuous output) but he is not able to do very much actual work because most of that energy goes to lifting his own weight. Women pumping water from a well (with their arms and upper body) can put out about 40 watts for quite a long time (over a hour). It is a fact that people are “harnessed” to the work by their tools. A harness that is properly shaped makes the work much easier.

Working against a constant resistance gripping a handle is hard on the human body. The force required by a hand tool should be held below 20 Kg where possible. 10kg is preferable. This is an important consideration when designing something like single-wheeled wheelbarrows. The balance of the barrow is important because if the handle pull downwards combined with force from the body leaning forward to move the load is excessive, the labourer will get tired arms very quickly. A well designed two wheeled barrow carries far more soil than a single-wheeled model for the same arm load and energy input. Four-wheeled carts, or even three wheeled ones, are a very effective use of human labour because all the available “push” can be applied to moving the load rather than holding it up off the ground. In China, bicycles are sometimes used to transport baskets of soil, turning it into a two wheeled cart. After dropping the load on site, the labourer then rides the bicycle back to the burrow pit. This also minimises his effort when travelling. I am sorry that I do not have a figure for the efficiency of that combination so I could compare it with carrying a basket of soil on the head and walking back, but obviously it is a lot less work to use the bicycle.

2.8.2.2 Available power - Oxen

An ox can be used to do various tasks. The continuous pull should not exceed 50 kg and it should work for only five hours per day. The output (continuous) is about 245 watts, or about the same as three people. Note that the pull (50 kg) is about three times a human’s pull (20 kg). As the walking speed is similar, one can deduce that the figures are correct. Yoking two oxen together only increases their available pull by 50%, even using a yoke with an adjustable pulling position.13

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13“With 2 oxen yoked together you are lucky to get 1,5 times the work of 1.” Roman Imboden, ARDETEC Pump Designer, Ndounga, Niger
Two oxen can exert about 75 Kg force on the harness and put out about 365 watts continuously.

### 2.8.2.3 Available power - Donkeys

Donkeys are very efficient users of available grazing and can work for longer periods than oxen - about 8 hours per day. They can pull a 25 kg load and put out about 135 watts continuously and move faster than an ox. This enables a smaller, less thirsty donkey to accomplish about the same amount of total work during a day as a much larger ox, but only if the tools are suited to the lower pull, and can take advantage of the higher walking speed (0.9 metres per second compared with the ox’s 0.6 metres per second). You cannot harness a donkey to ox-drawn implements and automatically expect a similar amount of work to be done. The tools have to be suited to the weight, speed and temperament of the animal.

### 2.8.2.4 Tools and technique efficiency

Human labour is a valuable resource and not to be wasted. It should be clear that the optimal use of available labour requires some deep thought about speed, load, rest and the task type, not to mention motivation. It is my opinion that this has not been very well researched. There are hardly any tools that are well suited to road construction by hand. Masses of money have been spent researching machinery and making it efficient, but one does not hear of attempts to seriously improve the tools for labour-based road construction.

I will give you an example. Correct tamping of the surface of a road is a very important function as it will determine the density and durability of the final product. Here is a design decision: Should the tamper be raised from the ground by hand (adding potential energy as it rises) and dropped to impact the ground, or should the tamper be mounted and counterbalanced in some device that makes it float in the air? The operator of the device would drive the tamper down and it would hit the ground at the same speed as if it had fallen from the same height. Per unit input of energy, which provides more tamped area per day and to what density?

I have never seen a counterbalanced tamping device. If it existed, it would relieve a lot of the strain on the forearms of the labourers and allow them to pull down on the tamper - a far more efficient motion than lifting a vertical pipe. It is this type of imagination we need to greatly increase the output of the road worker. Simple, strong and labour-efficient tools may make all the difference between an economic success and the dustbin of history. We cannot afford to fail. The revitalisation of the rural economy may well depend on labour-based civil works projects.

### 2.8.3 Basic Technical Advice from the Design Table

Africa is hard on equipment. In particular, on bearings, rigid things, engines and vehicles - even animal drawn ones. If something is going to be used as a tool to earn a living, it must be made to last. Alternatively, it must be able to be easily replaced in the local environment. My preference these days, with markets opening up and borders becoming less crazy, is for quality and long life before continuous, nagging breakdowns. Where possible, make things so they will never
break. Africa is covered with those failed machines in the jungle we have all heard about, but also with very well made old, old machines from the UK and Germany that have worked for 100 years. If we are going to manufacture machines in Africa for African conditions, we will make simple, rugged, largely maintenance-free machines.

All tools get abused at one time or another. They should be designed so that a human cannot ordinarily break them. An example of this is the Rock Crusher from New Dawn Engineering. It is sized to make life easy for the operator in terms of rolling resistance. If, however, the operator encounters a large hard rock that he is determined to break, he might spin the flywheel up to 180 rpm and drop it into the jaws. If it fails to break the rock, the flywheel will come to an almost immediate stop after a few degrees of rotation. The main shaft, keyways and bearings have been built to cope with just that scenario and survive unscathed. The flywheel could be increased in size to make the crushing easier, but that would put the bearings and main shaft at risk. No one has broken a Rock Crusher yet.

Here are some other considerations for the African tool designer.

2.8.3.1 Bearings

I am sure we are all aware of the use of blocks of hardwood in some countries as a substitute for ball bearings. These blocks are soaked in oil and will work for some time. They are easily replaced and very cheap. Equipment sized to human proportions does not often require high capacity bearings so wooden ones will do very well.

Other materials that work well include Vescanite. This is a plastic bushing material that does not need to be greased. I have found that it is easy to work with, very long lasting when oiled with anything from shea butter to cooking oil to engine oil. It can be purchased in tube form and pressed into steel tubing. In this way you can easily make axles from stock materials without any machining. It is also available in bars and sheets so you can machine anything you like. Vescanite should not be loaded higher than 750 pounds per square inch. There should be an interference fit of 0.2mm on pressed bushes. The minimum wall thickness is about 4mm. Pre-machined bushes are available in sizes 0.2mm above the nominal steel bar size. For example, a 40.2mm x 32.2mm bush presses into a 40mm hole, and the inside diameter comes down to 32.0mm. This can take an ordinary 32mm bright shaft which normally measures 31.95mm. Vescanite gives a far longer life to a simple axle than a steel bar running in a steel tube.

Nylon, which is also available in tubes, sheets and bars, is not as good but might be more available. It tends to absorb water and change size so leave 0.2mm clearance between the bush and the shaft.

Another bearing type that is not often used but worth investigating is the plain spherical ball bearing. This is a single spherical ball turning in a seat made of steel or bronze. The longest lasting and most robust ones are the steel-on-steel with PTFE linings and a seal on each side. We use these on the rock crusher’s main shaft. They have very high load ratings (30mm = 30 tonnes) and can take enormous abuse without complaint.
The simple roller bearings found inside wheelbarrow wheels are suitable for making lower quality hubs on steel shafts. The rollers, even home-made ones, can be a lot better in terms of rolling resistance than plain steel on steel. Rollers can be bought from bearing suppliers.

Lastly, bearings are sold at greatly inflated prices. It is usually possible to negotiate discounts from the “list price” of up to 75%. Generally speaking, the “Y” series of bearings (with pedestals and flanges) have greater discounts than plain bearings. I pay less than US$10 for a sealed 30mm pillow block (UCP 206).

2.8.3.2 Axles

There are a number of ways to make axles, but a little known fact is that there are axle stubs available that can be welded onto the ends of pipes to make axles as good as factory products. These stubs take standard bearings for cars and can accept car wheels as well. Brakes are needed on axles where soil is being transported downhill. The rating of the brakes should exceed the load by 100%. This applies to the axle itself as well. For example, a one tonne cart that will actually transport one tonne of stone down a hill all day, should preferably have a two tonne axle and brakes.

Fully manufactured axle kits can be purchased at surprisingly low cost as complete units with or without brakes. The brakes are available as lever or cable types.

I have made axles with only one wheel hub. These are very simple and allow for a differential effect with plain surfaces. The axle bearings are good quality, the hub bearing of the lowest because it does not turn very much.

Do not use a square tube for an axle. A round tube with the same amount of steel in it is slightly cheaper and 26% stronger.

2.8.3.3 Abuse

As mentioned before, the tools should be designed with the human limitations in mind. In spite of all the stories, people are only capable of delivering a certain amount of energy to the tools. The tool should be able to survive that. Going for the lightest design possible is sometimes important but not nearly always. It has been said that an engineer is a person who can do for half a crown, what any fool can do for a pound. Unfortunately, we do not have very many engineers designing road making tools. Modern materials and mathematical skills should allow us to make tools that cost only half a crown, but last as if they cost a pound.

2.8.4 Materials for Tools

2.8.4.1 Availability

It is frequently said that materials for making good tools, such as some I have already mentioned, are unavailable in the area where the road works are located. I am willing to bet that you can get radios, watches, video players, batteries, petrol and Nike shoes in those areas, so what is the problem? A government that wants to seriously do something about labour-enhanced civil works has to make some effort to get the materials for tool-making businesses. It is far cheaper to import materials for making tools than it is to import heavy equipment and feed and
maintain them for years. Capital equipment is imported all the time into many
countries. A lot of effort is made to see that fuel is available and staff trained.
Why shouldn’t this effort also be made to create mass employment? The social
and economic benefits of a high employment rural economy will surely attract the
interest of importers and economic regulators.

2.8.4.2 Importation of tools

Further to this issue is the fact that many countries allow the importation of large
plant and machinery tax free or tax reduced. It has always been surprising to me
that most countries fully tax small tools and materials to make tools, but exempt
big machines. The ordinary citizens are the ones who will make, buy and use the
smaller tools. They also find themselves in competition with capital intensive
industries, yet only the largest are given a tax break. In one African country,
locally produced production equipment is taxed, but imported equipment is not.
This is because no one envisaged anyone would ever produce production
equipment in that country. The result is that there is a preference for imported
machines.

This issue is so important that it would be good if the delegates present at the
conference would raise the issue in their home countries with the customs office.
It should be easier to import components and tools than finished products and
finished goods. Small industries are the main employers and they deserve the
support of central government. Tools and equipment are only useful for creating
wealth. If the main components like bearings and steel are unavailable, the
government has no choice but to import the finished articles. It is high time the
equipment industry received fair treatment at the hands of central government.

2.8.5 Fencing and Gabions

2.8.5.1 Fencing

All fencing made from wire can be hand made. New Dawn Engineering in
Swaziland has a complete range of equipment for making Diamond Mesh, Barbed
Wire, Game Fence, Chicken Wire, Pig Wire and other types called Diamond
Stucco Mesh, Square Mesh and even floor tile reinforcement. Wire products are
easy to make on a small scale. Road fences, where they are put up, should be
made and erected by the people living along the road. The Gazankulu Roads
Department in South Africa erected some 200 km of goat-proof fence along
some main roads. All of it was made in the villages that the roads passed.

2.8.5.2 Gabions

Gabion structures are more common in mountainous areas where water erosion is
a problem, but they can be found everywhere. All gabion baskets, cages and
Reno Mattresses can be hand made. Some are made using Diamond Mesh, but a
new type of hand made fence called Tri-Net has been developed specifically for
the gabion market. It is made on a steel jig that should last a lifetime. Swaziland’s
drought-relief inspired “food-for-work” programme has made use of this
technology to build civil works structures and for erecting goat-proof fencing as
well. All the gabion making technologies can be produced locally in a welding
shop.
2.8.6 Management of Construction and Maintenance

The skills required to build a road with a lot of capital equipment are quite different from the skills required to manage a labour-based project. The training in equipment use is also very different. Generally speaking, a capital equipment-based project is professional-intensive, and a labour-based project is management-intensive. As professionals are generally not trained to handle management-intensive activities, there is a likelihood that a labour-based project will have training problems as well.

It takes skill to build a road. The road design, the layout of parabolic curves, the curvature and slope of the topping, the layout of drains - all require that the workers understand why and what they are doing. Perhaps you have seen a roadside team with five people standing idle watching another one or two work. This is death to the system. Developing a team spirit and teamwork requires practice and motivation. Training in the correct use of tools is critical. Generally, the simpler a tool, the more the technology required to make it effective lies in the hands of the worker.

An example of this is the loading of coal into the boiler of a steam engine. It sounds simple, but it takes some time to learn how to shovel in the coal in a way that keeps the fire burning evenly over the surface of the firebox. The shovel used to accomplish this is a special shape and bent at a particular angle. Ordinary shovels are not suitable. It is quite possible that the even spreading of crushed stone over a road surface when tarring would require the same shape of shovel and type of training as the steam engine fireman.

For each tool there are techniques. For each technique there are levels of perfection. In short, training of workers to be efficient can make all the difference between making a good or a bad start. The management of the tools and workers can make the difference between success and failure of the whole project. It is very likely that the best trainers of new workers are not road “experts” but others experienced in that particular art - quite ordinary people. Some workers will develop a new technique that would be further assisted by a change in the tool. These innovations must be encouraged and disseminated. Of particular interest are loading tools for soil and sand, and compacting tools. It is frequently feared by the engineers that compaction will not be up to standard and that gives rise to resistance to a new project or technique.

2.8.7 List of Materials Required for Tool Manufacturing

- Steel tubes, hot rolled sections, plates, flanges, round bars both black and bright
- Spring steel (EN45 or SAE 9255) flat and round bars
- Welding rods including hard facing rods
- Sand and cement (to make weights)
- Wood for beams, boxes and canopies
- Wood for bearings
- Bearings - many types but especially plain spherical balls and pillow blocks (SY series)
• Nails and nail wire (which is much harder than ordinary wire)
• Bolts, washers and nuts including nylock nuts
• Circlips and cotter pins
• Plain galvanised wire
• Stone for ballast
• Tires and tubes, rims and spokes
• Steel cable (pulleys can be made)
• Chain
• Paint and thinners
• Reflectors and Chevron signs

2.8.8 List of Skills Required for Tool Manufacturing
• Welding, both arc and gas
• Cutting, both arc and gas
• Basic fitting and turning skills - This includes knowing how to cut circlip grooves and thread shafts
• Simple carpentry skills
• Basic forging skills - can also be applied when welding is difficult or unavailable
• At least some knowledge of heat treatment
• Ability to select and order bearings based on estimated loads
• General knowledge of available sizes of steel sections, bearing sizes, circlips and bolts
• Ability to make and read simple drawings & maintain a library of drawings & photos

2.8.9 Opportunities for Tool Designers
As so little is spent on research and development seeking higher quality solutions for labour-enhancing technologies, the field is basically wide open. Anyone wanting to get established in the field should aim to become an “undifferentiated generalist” not a specialist. It requires an interesting combination of studying old ways, keeping abreast of new developments in materials, developing mathematical modelling skills, getting your hands dirty in the field and wearing clean shirts in the boardrooms.

Some of the best books to have at hand are:
• Comprehensive bearing catalogue from any major manufacturers - SKF, FAG, Fenner
• Complete list of available metric and imperial steel sizes, preferably together with the Moment of Inertia and area figures beside them
• Complete list of steam & water pipe & flange dimensions
• Machinery Handbook - an absolute must and the most useful of all
• Machinery Handbook companion volume which explains how to use the main volume
• Speciality steel catalogue from one of your suppliers listing uses and heat treatments for different types of steel
• Notebook where you keep with soil, sand and stone densities, sand grading profiles, conversion factors and so on.

So, in a nutshell, that is the end of the talk and, I hope, the beginning of a whole new career for you!
Appendix 1

Basic work outputs from man and animal


The accompanying table gives results obtained by Poncelet, Morin, Rankine, and others. The work by Dr. F. W. Taylor shows that a maximum amount of shovelling may be accomplished by the use of a shovel taking a load of 22 lb [10 kg]. Also that by the introduction of rest periods at stated intervals (determined from a study of the particular task), the amount of work done in a day by a labourer may be greatly increased above the figures given.

Note: The following figures are measured. The [figures] are calculated.

<table>
<thead>
<tr>
<th>Nature of work</th>
<th>Weight moved or resistance overcome</th>
<th>Velocity of movement ft. per second</th>
<th>Work done per sec.</th>
<th>Time of working hours per day</th>
<th>Work done per day ft-lb</th>
<th>Work done per day KWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raising Weights</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Man raising his own weight up a stair or ladder</td>
<td>143</td>
<td>0.5</td>
<td>71.5</td>
<td>8</td>
<td>2,059,200</td>
<td>[0.776]</td>
</tr>
<tr>
<td>Man hoisting weight with rope and pulley, and lowering unloaded rope</td>
<td>40</td>
<td>0.66</td>
<td>26.4</td>
<td>6</td>
<td>570,240</td>
<td>[0.215]</td>
</tr>
<tr>
<td>Lifting weights by hand</td>
<td>44</td>
<td>0.56</td>
<td>24.6</td>
<td>6</td>
<td>531,360</td>
<td>[0.200]</td>
</tr>
<tr>
<td>Carrying weights on the back up stairs or a ladder, returning unloaded*</td>
<td>143</td>
<td>0.13</td>
<td>18.6</td>
<td>6</td>
<td>401,760</td>
<td>[0.151]</td>
</tr>
<tr>
<td>Pushing loaded wheelbarrow up a 1:12 incline, returning unloaded</td>
<td>132</td>
<td>0.065</td>
<td>8.6</td>
<td>10</td>
<td>309,600</td>
<td>[0.116]</td>
</tr>
<tr>
<td>Shovelling up earth: lift 5ft 3 in. [1.576m]</td>
<td>6</td>
<td>1.3</td>
<td>7.8</td>
<td>10</td>
<td>280,800</td>
<td>[0.106]</td>
</tr>
</tbody>
</table>

Dr. Taylor ("Principles of Scientific Management," p.60) cites the instance of a labourer lifting and carrying 1,156 pigs of iron (each weighing 92 lb [41.7 Kg]) up an incline into a [rail] car during a 10 hour day. Average distance of travel, 36 ft. [11 M]; total lift (probably not less than) 8 ft. [2.4 M]. Ft.-lb of work (lifting) = 8 X 1156 X 92 = 850,816 Ft.lb [0.321 Kwh nett work accomplished]. Prior to a study of the task and the introduction of proper rest periods, the best day's accomplishment was the transporting of 305 pigs. ibid., p.864
Appendix 2


**Operating machines and tools**

Note: The following figures are measured. The [figures] are calculated.

<table>
<thead>
<tr>
<th>Nature of work</th>
<th>Weight ( w ) moved or resistance overcome</th>
<th>Velocity of movement ( \text{ft. per second} )</th>
<th>Work done per sec.</th>
<th>Time of working hours per day</th>
<th>Work done per day, ft-lb.</th>
<th>[Work done per day KWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pushing or pulling horizontally and continuously (capstan or oar)</td>
<td>26.4</td>
<td>2.0</td>
<td>52.8</td>
<td>8</td>
<td>1,520,640</td>
<td>[0.573]</td>
</tr>
<tr>
<td>Pushing or pulling alternately in a vertical direction (pump)</td>
<td>13.2</td>
<td>2.5</td>
<td>33.0</td>
<td>10</td>
<td>1,188,000</td>
<td>[0.448]</td>
</tr>
<tr>
<td>Turning a crank</td>
<td>17.6</td>
<td>2.5</td>
<td>44.0</td>
<td>8</td>
<td>1,267,200</td>
<td>[0.477]</td>
</tr>
<tr>
<td>Horse operating a horse gin, walking</td>
<td>99.0</td>
<td>3.0</td>
<td>297.0</td>
<td>8</td>
<td>8,553,600</td>
<td>[3.223]</td>
</tr>
<tr>
<td>Figure for an ox</td>
<td>132.0</td>
<td>2.0</td>
<td>264.0</td>
<td>5</td>
<td>4,752,000</td>
<td>[1.790]</td>
</tr>
<tr>
<td>[Metric Figures for an ox]</td>
<td>59.8 kg</td>
<td>0.61 M/s</td>
<td>36.5 KgM/s</td>
<td>5</td>
<td>656,604</td>
<td>[1.790]</td>
</tr>
<tr>
<td>[Figure for an ox @ 8 hours]</td>
<td>132.0</td>
<td>2.0</td>
<td>264.0</td>
<td>8</td>
<td>7,603,200</td>
<td>[2.865]</td>
</tr>
<tr>
<td>Figure for a mule</td>
<td>66.0</td>
<td>3.0</td>
<td>198.0</td>
<td>8</td>
<td>5,702,400</td>
<td>[2.148]</td>
</tr>
<tr>
<td>Figure for a donkey</td>
<td>31.0</td>
<td>2.6</td>
<td>80.6</td>
<td>8</td>
<td>2,902,245</td>
<td>[1.093]</td>
</tr>
<tr>
<td>Horse operating a horse gin, trotting</td>
<td>66.0</td>
<td>6.6</td>
<td>436.0</td>
<td>4.5</td>
<td>7,063,200</td>
<td>[2.661]</td>
</tr>
</tbody>
</table>
Appendix 3


**Human labour applied to various tasks**

Note The following figures are measured. The [figures] are calculated.

<table>
<thead>
<tr>
<th>Nature of work</th>
<th>Weight w moved or resistance overcome</th>
<th>Velocity of movement ft. per second</th>
<th>Work done per sec.</th>
<th>Time of working hours per day</th>
<th>Work done per day, ft-lb.</th>
<th>[Work done per day KWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transporting loads horizontally man walking unloaded</td>
<td>143</td>
<td>5.0</td>
<td>715</td>
<td>10</td>
<td>25,740,000</td>
<td>[ 9.698 ]</td>
</tr>
<tr>
<td>Man wheeling load w in a 2-wheeled barrow, returning unloaded</td>
<td>220</td>
<td>1.7</td>
<td>374</td>
<td>10</td>
<td>13,464,000</td>
<td>[ 5.073 ]</td>
</tr>
<tr>
<td>Man wheeling load w in a 1-wheeled barrow, returning unloaded</td>
<td>132</td>
<td>1.7</td>
<td>224</td>
<td>10</td>
<td>8,064,000</td>
<td>[ 3.038 ]</td>
</tr>
<tr>
<td>Man travelling with load w on back</td>
<td>88</td>
<td>2.5</td>
<td>220</td>
<td>7</td>
<td>5,544,000</td>
<td>[ 2.089 ]</td>
</tr>
<tr>
<td>Man carrying load w on back, returning unloaded</td>
<td>143</td>
<td>1.7</td>
<td>243</td>
<td>6</td>
<td>5,248,800</td>
<td>[ 1.978 ]</td>
</tr>
<tr>
<td>Throwing earth with a shovel a distance of 13 ft [4 M]</td>
<td>6</td>
<td>2.2</td>
<td>13.2</td>
<td>10</td>
<td>475,200</td>
<td>[ 0.179 ]</td>
</tr>
<tr>
<td>Horse drawing cart loaded with w, walking</td>
<td>1540</td>
<td>3.6</td>
<td>5544</td>
<td>10</td>
<td>199,584,000</td>
<td>[75.197]</td>
</tr>
<tr>
<td>Horse drawing cart loaded with w, trotting</td>
<td>770</td>
<td>7.2</td>
<td>5544</td>
<td>4.5</td>
<td>89,812,800</td>
<td>[33.839]</td>
</tr>
<tr>
<td>Horse walking with loaded cart, returning empty</td>
<td>1540</td>
<td>2.0</td>
<td>3080</td>
<td>10</td>
<td>110,880,000</td>
<td>[]</td>
</tr>
<tr>
<td>Horse carrying burden w walking</td>
<td>264</td>
<td>3.6</td>
<td>950</td>
<td>10</td>
<td>34,200,000</td>
<td>[]</td>
</tr>
<tr>
<td>Horse carrying burden w trotting</td>
<td>176</td>
<td>7.2</td>
<td>1267</td>
<td>7</td>
<td>31,928,400</td>
<td>[]</td>
</tr>
</tbody>
</table>

"The draft of horses is reduced by working them in teams. The draft of a horse in a 2 (4) [8] horse team is but 98 (80) [49] per cent. of that exerted by the horse when working alone."
2.9 THE RIGHT TOOL FOR THE JOB, REVIEW OF TOOLS AND EQUIPMENT FOR LABOUR-BASED INFRASTRUCTURE WORKS: THE FIT PROGRAMME EXPERIENCE

Enoth Mbeine, Liaison Officer, FIT Uganda, MTAC, Nakawa, P. O. Box 24060, Kampala, Uganda. email: fituga@imul.com

2.9.1 Fit Programme

The FIT Programme is a technical assistance programme implemented through the ILO in Geneva. The FIT programme has been working in Kenya and Ghana for over three years to develop new and innovative approaches to the development and delivery of non financial business services to MSEs. From its work in Kenya and Ghana, FIT has developed a number of effective mechanisms for providing new and improved services and is now in the process of disseminating these to six other African countries.

2.9.2 FIT Uganda

FIT Uganda was established in February 1997 to introduce and adapt the FIT mechanisms to Uganda, and develop other new and innovative approaches to business services development.

2.9.3 User Led Innovation Methodology

User Led Innovation (ULI) activities were developed by the FIT Programme and have been successfully implemented in both Kenya and Ghana. ULI in essence, is a practical introduction of producers to the product development process. The activity involves a series of workshops and meetings which take the participants through a design process where new and improved products are suggested by the potential end users and customers.

Using the ULI approach, the end users can give the producers enough information to build innovative products. Ideally, they may also be the first customers for the prototypes, at the same time providing funds for further development as well as feedback on the performance of the new or improved products. The incorporation of local knowledge into the development of technological solutions, and the consequent ownership of the results, are two very important factors in favour of a participatory approach.

2.9.3.1 Methodology Sequence

Step 1- Identification of participants (a group of producers or their representatives and their existing and potential customers).
Step 2- One half day meeting between the producers or their representatives and one half day meeting between the users/customers to identify objectives and clarify the purpose of the activity. (orientation of participants).

Step 3- One full day workshop bringing customers and end users together to identify the customers’ needs for new and improved products and services. (brainstorming on new and improved products).

Step 4- Follow up workshops of participants to analyse the findings of the user/manufacturer (or representative) meeting, identify potential new and improved products and draw up an action plan (product identification).

Step 5- Small financial support provided to producers to prototype the identified new and improved products. Prototypes produced by manufacturers (product prototyping).

Step 6- Workshop for the manufacturers (or their representatives) to present their prototypes to the potential end users and customers. (product launch/testing).

User led innovation activity can be applied to a variety of sectors. This methodology applies to MSEs but this kind of experience could be very useful in the development of appropriate equipment for end users in Uganda. The equipment that cannot be manufactured locally in Uganda, should have some design recommendations by the end users. Here the representatives of the tool manufacturers should collaborate with road constructors who in turn should forward the appropriate designs for equipment in their respective areas.
2.10 EXPERIENCE IN LABOUR INTENSIVE AND EQUIPMENT BASED ROAD AND CANAL CONSTRUCTION WITH GEOCELLS

G J R van der Meulen and * A R M Hall, MABER General Consultants and Business Brokers, 3 Orchard Heights, Newlands 7700, South Africa; * Managing director, Manufacturers of HYSON-CELLS, P O Box 319 Muldersdrift 1747, South Africa

Summary

In the process of building the infrastructure, a premium is being paid for helping people bridge the development gap between agricultural existence and the industrial age. It is the task of the better educated members of society such as the technical and administrative personnel of local authorities to optimise the premium the population as a whole is paying via rates and taxes. Local manufacture of and expertise in the use of Geocells allows good, durable roads, ponds and canals to be built economically with a wide range of manual labour content to suit a wide range of conditions. A number of case histories are presented to demonstrate how the premium has at times been wasted and at other times has been fully utilised to enlarge the human capital of this country.

2.10.1 Introduction

Just as children cannot skip being teenagers before they become adults, all nations have to progress through stages of development.

After learning to make hand implements, mankind developed more sophisticated equipment to accomplish much work with little effort.

That is why it has become possible to build roads and canals economically and efficiently with capital-intensive equipment and a low labour content.

As the labour force has a tendency to strike, it is not surprising that some of the established contractors are not enthusiastic about and may even merely pay lip service to calls to involve local labour for community projects. This is particularly likely if the contractor is held responsible for the quality of the work and timely delivery and might face penalties over and above losses he might incur if the untrained and inexperienced labourers are uncooperative.

It has been accepted by the powers that be, that a premium cost over and above efficient economic industrial first world construction techniques is a small price to pay for peace and quiet when infrastructural projects have to be constructed in or for recently established communities.
2.10.2 The Aim of this Paper

Our aim is to show that through creative thinking, enthusiasm and utilising the energy and desire of people to improve themselves without losing sight of selfish and greedy behaviour, it has been possible to contain costs of infrastructural work so that more money is available for housing. As part of the construction project, the opportunity should be grasped to make it a valuable learning experience for members in the community, not only for learning new skills, but for appreciation that the quality of the work influences its useful life and therefore the benefit the whole community will derive from it.

2.10.3 Development

It was only recently that inhabitants in New Guinea emerged from the Stone Age because up till then those were the only implements they used in their mainly hunter-gatherer existence.

After man had become an agriculturist, he started to trade. As trade routes developed, money, its value system and uses and banking were developed.

With the coming of the industrial age, man was able to produce considerably more than he consumed.

In time, this excess wealth accumulated. We have inherited the wealth left by our predecessors and have added to that in our lifetime. This building we are in, the roads outside, the lights and electricity networks are but a few examples.

Most of the inhabitants of squatter camps have just left the agricultural stage of development and are expected to suddenly operate effectively in the industrial age, having completely skipped the lessons taught about the value system of money which is normally absorbed during the trading stage of development!

Therefore it behoves us to educate the people who are drawn into our projects, particularly labour intensive projects, to help them bridge the development gap and teach them the equation:

$$W = W(uku)S = (ubu)T$$

In English and Afrikaans - and in Xhosa

(work = wealth; werk = weelde) (ukusebenza = ubutyebi)

Most of us who have grown up in an industrial culture are used to "hiring and firing" and know that "output" and "productivity" are important factors in rating people and profit margins.

For us, "profit" is not a dirty word, because we know that there are four costs related to each product and that “profits” have to be “ploughed back” to provide the capital for survival and sustained growth. We also know that the less profit is set aside, the slower the development.

The four cost aspects are:

1. Cost of materials.
2. Cost of borrowing money to build the project.
3. Cost of salaries paid to the workers and the bosses.
4. Cost of the profit.

Unless people are taught that their perception that the profit is “merely an extra salary for the bosses” is incorrect, we cannot hope to improve productivity and efficiency.

For a chosen profit and cost of borrowing money (related to a national bank), people should be shown that if a particular project is completed with the least amount of waste of materials, it will leave more for salaries for both the workers and the bosses. Hence, there is an incentive for them to work together and maximise the benefits from the project.

We, in this room, understand the law of economics, known as the “law of supply and demand”, or rather we think we do. We believe that if something is in short supply, its value is high and if it is abundant, its value is low. Because all raw materials are finite in quantity and the labour force is infinitely renewable, all materials should be expensive and labour cheap when viewed in global terms.

However, from an individual's point of view one's life and therefore the hours of labour which can be sold is limited in comparison with the materials which are consumed in a lifetime and hence we rate labour expensive and do not mind wasting materials.

In the regions where there is the greatest need for infrastructure, we find the greatest concentration of people who have just left the agricultural age. A few spaza and taxi owners have entered the trading stage of development, even fewer industrial age.

Part of the reason for the problems which have arisen and are arising in labour intensive projects is that the participants have not taken cognisance of these factors.

2.10.4 What is Success?

Success is achieved when set objectives have been reached.

As town engineers, town clerks, designers and contractors, we are merely the administrators for the politicians who are our bosses and the tax/rate payers who are the financiers.

Is our objective to have a project built and provide employment to some nameless people to pander to promises made by politicians?

Or should our objective be wider? Should we do the above and at the same time help a few people to utilise this opportunity to bridge the development gap and hopefully in the process discover and grow some entrepreneurial material? Entrepreneurs in small firms are known to be the best creators of jobs. Should our objective also be to minimise waste of materials and the cost of borrowing money (penalties for late completion are a kind of measure of the cost of money) and thus allow us to spread the taxpayer's money farther and make the remainder available for housing?

Should our objective also include delivery of a good, sound, sustainable quality product which will minimise future maintenance costs because the community has
developed a sense of ownership and therefore will tend to protect their inheritance of the wealth of others from vandalism and abuse?

2.10.5 Geocells and Paving

Geocells can have hexagonal cells like a honeycomb or more or less square cells. The heights of the mats generally range from 50 to 200mm but some of them can be manufactured up to 4000mm high.

A Geocell manufactured in this country has become so successful that it has given rise to competing products.

Geocells are not only used for building soil filled weirs, dams, earth retaining walls and vegetated bank protection but also, when they are filled with concrete, for building canal linings, spillways, pond linings, roads and container yards.

The walls of the cells can be porous or impermeable and can range in thickness from 50 micron to 4mm.

When the walls are porous and thin, the danger exists that the cement grout bonds the adjacent blocks and the final product behaves like a solid mass concrete slab.

When the walls comprise high density polyethylene or PVC, they act as a permanent formwork for individual blocks with minute evenly spaced joints caused by the shrinkage of concrete.

If the thickness of the polyethylene is less than 500 micron, the cell walls can deform enough to give sufficient three-dimensional interlock so that individual blocks cannot be punched through the paving nor be sucked out of canal linings.

Geocells generally do not have strings threaded through them. One locally manufactured Geocell with threaded polypropylene strings has withstood a patent infringement in America. The strings assist in holding up the walls of the mat when the cells are being filled and they are used to pull the mat onto the support media and so prevent a sheet of waste concrete under the cells. They help to create corrugations which improve the interlock and help to anchor mats to steep stable slopes.

When a three dimensional interlock between adjacent blocks is achieved, a paving resists point loads like chain-mail armour resisted spears and arrows in combat. Because the individual interlocking blocks can be made robust, it is not necessary to use reinforcing steel in paving and therefore aggregates contaminated with salt and calcium chloride based accelerators can be used with impunity.

Stretching of the Geocells mat and securing it to the support stratum prior to filling is done by hand. The preparatory and the subsequent work can be done either mechanically or manually. Consequently, a wide range of manual labour content can be accommodated in projects where Geocells are utilised.

For convenience, one supplier refers to four categories or working conditions as indicated in Table 1 for concrete paving.
2.10.6 Concrete/Grouted Stone Mixes and Strengths

Concrete comprises aggregates, cement, water and air.

Table 1: Working conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Equipment</th>
<th>Labourers per team</th>
<th>Materials</th>
<th>Production rate m²/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>First World</td>
<td>Backactor, front end loader, grout pump, concrete mixer or ready mixed truck, wheelbarrows and compactors.</td>
<td>8</td>
<td>Ready mixed concrete (±150mm slump)</td>
<td>200 - 800</td>
</tr>
<tr>
<td>Second World</td>
<td>Wheelbarrows, concrete mixer or Hippo roller mixers (Rotivator for stabilised materials) and compactor.</td>
<td>20</td>
<td>&quot;Wheelbarrow concrete&quot; Grouted stone Cement stabilised sand or soil</td>
<td>100 - 200</td>
</tr>
<tr>
<td>Third World</td>
<td>Wheelbarrows, Hippo roller mixers (Rotivator for stabilised materials) and compactor.</td>
<td>30</td>
<td>&quot;Wheelbarrow concrete&quot; Grouted stone Cement stabilised sand or soil</td>
<td>50 - 100</td>
</tr>
<tr>
<td>Fourth World</td>
<td>Hand operated stone crusher or hammers, wheelbarrows, Hippo roller mixers, (Rotivator for stabilised materials) and tampers.</td>
<td>60</td>
<td>&quot;Wheelbarrow concrete&quot; Grouted stone Cement stabilised sand or soil</td>
<td>???</td>
</tr>
</tbody>
</table>

Conventionally all these components are premixed at once before being placed in moulds but there should be no objection to changing the mixing and/or placing sequence as long as the end product is concrete.

It has been found that as soon as the cells are filled with soil or stone, the surface can be trafficked and therefore filling the cells with stone first and then with a sand, cement and water grout afterwards is a very practical way of achieving a concrete paving with unskilled people.

To minimise the air content (i.e. prevent honeycombing), the grout must be fluid, the stone clean and large and tamping or vibration is required to bring the air out.

The method is flexible because the grouting can be stopped at any convenient time and cell boundary and breakdown of the mixer does not stop the progress of other operations.

As people become more skilled and contractors wish to increase their production rates, a natural progression from Third or Second World conditions towards First World conditions tends to develop.

Concrete with 30 to 50mm slump which is suitable for normal concrete work, particularly where poker vibrators are used, is not suitable for use with Geocells. It compresses or collapses the cell walls (there is no easy way to establish this), reduces the resulting thickness of the paving and is difficult to spread.
Therefore concrete with a slump of in the order of 150mm must be used. (On steep slopes a slightly lower workability is more appropriate). Such concrete, however, usually segregates severely during transport in a wheelbarrow and separates into slush and a very stiff concrete. The latter collapses the cells when tipped. This can be overcome with air entrainers and other suitable additives as is done by the ready mix plants who now have "Hyson mixes" in their computers.

For Third World conditions the use of sophisticated additives is not appropriate and "wheelbarrow concrete" has to be used.

Because the sources of the aggregates vary widely, concretes with identical mix proportions and workability will exhibit different strengths. Where the strength of the concrete in say stormwater canals may not be critical, it may be easier and more appropriate to specify mix proportions as that is easily checked.

However, where strength is of importance such as in loaded road pavings, it is easier to specify a strength criterion. The appropriate mix proportions will then have to be established and checked by means of cores.

Mrs A.R.M. Hall was made "Concrete Woman of the Year" in 1995 by the Concrete Cement Institute for her contributions in this field of unconventional concrete work. It was found that for the kind of mixes used in grouted stone work the approximate strengths shown in Table 2 can generally be anticipated.

**Table 2: Grouted stone mixes**

<table>
<thead>
<tr>
<th>Sand : Cement ratio of grout</th>
<th>Order of Strength of grouted stone Mpa</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 : 1</td>
<td>± 10</td>
</tr>
<tr>
<td>2 : 1</td>
<td>± 20</td>
</tr>
<tr>
<td>1.5 : 1</td>
<td>± 30</td>
</tr>
<tr>
<td>1 : 1</td>
<td>± 40</td>
</tr>
</tbody>
</table>

It would appear that the initial interlock of the stone prior to grouting has a noticeable effect upon the compressive strength because if the same ingredients are premixed and placed in a cube mould, the compressive strength is less. Therefore coring is the best way of controlling the quality. A reasonable approximation can be obtained by prepacking stone in a cube mould and then tilting the mould on a corner while the grout is poured in so that no air is trapped as the mould is gradually placed horizontally during the grout being filled to the top. Placing the mould on a vibrating table disturbs the stone and changes the strength!

A slump cone is a recognised First World piece of equipment to control the workability of concrete. For Second and Third World conditions two litre plastic cool drink bottles which are readily obtainable can be used instead. When the bottom of such a bottle has been cut off and the bottle filled with concrete, the slump which results when the bottle is inverted, the top unscrewed and the bottle lifted, approximates the real slump done with a slump cone when the workability is about 150mm.
The same bottle can be used to assess the correct fluidity/flowability of the grout. The correct fluidity depends upon the absorption of the stone, its cleanliness and size as well as the depth of the cells. The fluidity should be such that two litres of grout should empty out of the neck of the bottle in 6 to 10 seconds to ensure full penetration of the stone bed.

Assistance from the supervising engineer/technician is required to establish the amount of water required for each of the “wheelbarrow concrete mixes” which straddle the strength which has been specified to give a 150mm “bottle slump”. Table 3 shows the approximate strengths which can be expected for the various mixes. This first mix is mixed conventionally on an impervious surface with the dry components being mixed first and the water being added until the desired slump has been achieved.

<table>
<thead>
<tr>
<th>Stone : Sand : Cement : ratio l :</th>
<th>Order of Strength of Concrete, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 : 10 : 2.50</td>
<td>± 15 to 26</td>
</tr>
<tr>
<td>10 : 10 : 3.33</td>
<td>± 27 to 39</td>
</tr>
<tr>
<td>10 : 10 : 5.00</td>
<td>± 40 to 54</td>
</tr>
<tr>
<td>10 : 10 : 10.0</td>
<td>± 53 to 65</td>
</tr>
</tbody>
</table>

Because wheelbarrows have a 30 litre capacity and segregation takes place during transport, the following procedure must be followed when concrete for use in Geocells is mixed on site:

Five litre plastic flower pots which have a hole in the bottom are used to measure the volumes of the materials because buckets are stolen.

Firstly, the cement and the previously established measured volume of water (plastic bottle containers) are mixed. 10 litres of stone is then added and mixed. The mixture is then wheeled to the casting area.

At the casting area, 10 litres of sand is sieved into the mix while it is being turned over. (Like sieving flour into a cake mix to prevent lumps, the sand has to be sieved into the mix to ensure homogeneity). When the mixing is completed, the concrete is immediately poured into the cells.

### 2.10.7 Case Histories

A number of projects have been selected and will be described briefly to show to what extent the wider objective discussed earlier may or may not have been met.

Some of the projects may act as an inspiration for others to simulate or build onto. Much of what has been learned is thanks to the enthusiasm and involvement of the people who were committed and were willing to move into uncharted waters.

### Case History No. 1

**Project Name:** Vosloorus Minor Stormwater Canal

**Scope:** 1,600m$^3$ - Ready mixed concrete in 200mm x 200mm x 100mm Geocells
Contractor: Protech Construction (Pty) Ltd

Contract Manager: Gerrit van Schalkwyk

Geocells Trainer: Paul Molapo

Consulting Engineer: Bradford Conning & Partners

The contract had specified that the contractor had to employ local labour. The local political party and the community structures had insisted that payment had to be on an hourly basis and this was incorporated in the documents.

When the project started, someone advised the local labour to work slowly and spin out the contract so that they would earn more. As this would have caused a loss to the contractor, he threatened to abandon the contract.

The trainer which the Geocells manufacturer supplied on that project, Paul Molapo, then acted as mediator and explained to the labourers and community members that unless a reasonable production rate was achieved, the contract would fail and they would earn nothing further.

This resolved a major crisis but the ultimate result was still a poorly constructed and finished canal with barely sufficient concrete on the one side where it had to be thrown by hand and too much on the other side where the ready mixed concrete truck had good access and the concrete was placed directly into the cells from the truck. However, if there was excess concrete it was merely spread and not worked forward as the work progressed.

Consequently, in my estimation, at least 10% to 15% more concrete was used than was required. The ready mixed plant was probably the main beneficiary.

This project probably only met the narrow objective and has left both the contractor and the consultant with negative feelings.

Case History No. 2

Project Name: Mfuleni Bulk Stormwater Upgrade

Scope: 17,000m³ grouted stone - 150mm x 150mm x 100mm Geocells

Contractor: Ken Stephens Construction (Pty) Ltd

Consulting Engineer: Gibb Africa

A minimum number of mandays of local labour had to be used by the contractor. The labour was paid on an hourly basis. They comprised the major portion of the labour force and three strikes occurred mainly for additional fringe benefits.

Initially, concrete mixers were used to mix the grout. Wheelbarrows and the front end loader bucket were used to carry the grout to the canal, but the productivity was low.

When the minimum requirement for the use of the labour had been met, the contractor had to reduce the labour force (not without pain) and employ ready mixed grout to increase the production rate in order to meet his completion date.

The contractor has accepted that "this is the way things are these days" and the narrow objective has been met. Hopefully, some of the retrenched workers may
have noticed that too much striking and low productivity lost them the wages they could have earned and which were ultimately paid to the ready mixed plant and its workers from “outside”. It is doubtful however if this lesson was learnt, unless someone pointed that out to them.

Case History No. 3

Project: Irrigation Drainage Canal - Upington

Scope: 7.4 km long, 7.5 m wide grouted stone - 200mm x 200mm x 75mm Geocells

Authority: Department of Water Affairs

Reference: Mr G Meiring

The construction of a much needed, overgrown and choked drainage canal in the irrigation system had been delayed. There was a clash between the use of the canal by farmers and the access required by the Department to construct a conventional trapezoidal reinforced concrete canal.

The canal was built under Third World conditions by a team of 12 permanent employees supplemented by five to six labourers seconded by each successive farmer along the canal.

It has been estimated that the project cost the Department about R150 000 less than conventional construction.

Although the casual farm workers were probably not assisted in bridging the development gap, the project was partly successful in the broader objective because tax payer’s funds were saved in comparison with the conventional approach.

Case History No. 4

Irrigation Canal: Pongola

Scope: 1.2 km with 10m perimeter and 2m deep 20 MPa ready mixed concrete 150mm x 150mm x 100mm Geocells

Authority: Department of Water Affairs

Reference: Mr B Bosman

Through a misunderstanding, the use of a particular type of Geocells had been banned in the department until Mrs Hall had discussions with Minister Kader Asmal. It was then decided to install a trial section in one of the new canals being constructed.

The results were sufficiently promising despite the initial low production rates at the start of the learning curve, that it was decided to build another portion of the work.

The normal production rate to build this conventional trapezoidal canal with doubly reinforced concrete panels and rubber expansion joints averaged about 350m²/day with First World equipment and a trained labour team of 60.
With concreted Geocells peak production rates of 1,100m²/day were reached with a team of 18 when the consistency of the ready mixed concrete, which could be delivered on both sides of the canal, had been optimised. The cost of the finished canal lining was about one-third that of the conventional construction.

This indicates the potential economies of scale obtainable with First World production and therefore indicates the kind of premiums we are paying for helping people over the development gap.

**Case History No. 5**

**Project Name:** Vosloorus Ext 14 - Stormwater Canal

**Scope:** ± 10,000m² to date - ready mixed concrete - 200mm x 200mm x 100mm Geocells

**Contractor:** Emergent Contractors

**Consulting Engineer:** Stewart Scott

**Reference:** Mr R Stone

The project was divided into sections with the intention of not only building the canal but also of creating new contractors.

The raw labour force was trained in the use of Geocells and concrete and the concept of task based remuneration. As this was initially not understood, there were some stoppages and problems at the start. Also it was difficult to instil pride and overcome an attitude of "if it is not right, that is just tough".

At the start, laying rates in the order of 70m²/day were achievable when the earthworks were ready.

When the first section had been completed, the 15 embryo emerging contractor groups which had been trained up consolidated into four firms which tendered on the basis of their own estimated production rates. The firms are paid and retention is withheld in the conventional manner. The production rates are now about double the initial rates. Not only is the canal being completed, but the wider objective of bridging the development gap is taking place.

**Case History No. 6**

**Project Name:** Kwamashu Road

**Scope:** 6,000m² grouted stone 200mm x 200mm x 100mm Geocells 2,000m² grouted stone 200mm x 200mm x 75mm Geocells

**Contractor:** W K Construction

**Reference:** Mr A Flemming

The roads were constructed on G5 and G6 material and finished with a broom finish.

The stone was 37.5mm size and the grout was three buckets of sand to three buckets of cement with ± 30 litres of water. Initially the grout was mixed in a concrete mixer and production was low.
Hippo roller mixers were then tried. A team of men measured the material into the roller mixers and women pulled them to the working face at roughly the same production rate as before but this improved later. The mixers worked well except that the holes where the handles fitted had to be modified.

At the negotiations with the community, it was agreed to pay on a task rate per day related to a production rate of 100m²/day, i.e. effectively at a rate per square meter produced.

Initially, the production rates were low but improved with time, because there was a willingness to try an entirely new approach.

A serious problem existed with theft of cement.

This indicates that the project merely achieved the narrow objective as there clearly still existed a “steal from them for us” attitude and no incentive or flexibility existed to reduce costs for the taxpayer nor to increase benefits for the recipient community as a whole.

**Case History No. 7**

**Project:** Township roads in Eluxoliweni

**Scope:** 3,000m² grouted stone 150mm x 150mm x 75mm Geocells

**Authority:** Municipality of East London

**Reference:** Mr S Schroeder

The need had been established to surface steep gravel township roads which washed away in the rain.

It was decided to try grouted stone Geocells construction, although its initial cost was estimated to be higher than a single seal bitumen spray, because the latter was not expected to give long term service.

The then roads design technician, Mr Schroeder, was involved in the initial negotiations with the community and the execution of the work.

He had initial problems during the setting out of the works when one of his labourers was attacked and also later when the Sotho trainer, Joseph Nyembe, who was sent by the Geocells manufacturer to train the construction team, was attacked.

Mr Schroeder took the matter up with the then community leader (who is now the deputy mayor of the town) and told him to sort out his community or otherwise the roads would not be built.

This caused quite a furore but resulted in support from the community.

In addition to the equipment, municipal overalls were supplied to the workers, which helped to give them status. The grout was supplied from a ready mixed truck.

In the beginning, the informal leader of the group of workers was assertive and caused trouble. However, he served as the communication channel through a message was transmitted that enough money was available to build two roads from which they would earn a part. However, if they worked harder, they would
still earn and they might be able to build further and the community as a whole would reap the benefits. In the event three roads were built from the budgeted funds.

When there was a problem with the finish of the work, Mr Schroeder asked them, whose road it was - his or theirs? This caused some embarrassment and the quality of the work immediately improved again.

The obstreperous leader was afterwards recommended for work in a sweet factory and is reported to be a star.

This project clearly can be rated as a highly successful project because it has achieved practically all the objectives enumerated above and demonstrates the importance of personal commitment of all the participants, which included the leaders in both the then council and the community.

2.10.8 Conclusion

Because the labour content is a high proportion of the cost of infrastructural work and its quality effects the service life of the facility, it is important to create the right attitude in the labour force and a sense of ownership in the recipient community.

Case history no. 4 demonstrates that the most efficient manner of building the infrastructure in this country is by means of large scale First World techniques.

However, with that process, we will not address the development gap, which has to be done to create peace and prosperity and therefore we have to accept that a premium must be paid for education while we build the infrastructure a little slower. This education is a painful process, particularly for the students.

As teachers we have the choice of how to spend the premiums in one of two ways. One way is to spend it at the start of a project and invest it in good communication and offer a bonus to the community as a whole by providing more for the same money in the end.

Alternatively, we can allow matters to take their course and the premium will be spent on waste, theft, work stoppages, financial losses and interest to financiers and although the few employed labourers may have gained individually some more money for uninspiring work in the short term, they will not have developed pride and long term knowledge and skills.

The responsibility of that choice is ours as the administrators for society.
3 EQUIPPING CONTRACTORS AND PROJECTS
3.1 CHOICE OF HAULAGE EQUIPMENT FOR LABOUR-BASED ROAD WORKS

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Email: norcon@form-net.com

3.1.1 Introduction

Discussions on the most suitable type of haulage equipment are perhaps as old as labour-based rural roads programmes themselves. The extent of possible options ranges from moving material on head-baskets, wheelbarrows, animal drawn carts, tractor/trailer combinations to the haulage of gravel by flatbed or tipper trucks. It is felt that these debates are often based on personal beliefs rather than on actual facts valid for specific and current project situation.

This paper therefore highlights factors to be considered when selecting haulage equipment based on sound economic reasoning. Particular emphasis is given to issues for which circumstances might have changed over the years. Conclusions made are based on present conditions and are applicable to a number of African countries including Uganda, Tanzania, Kenya and Zambia.

3.1.2 Haulage as a Component of Total Construction Costs

Although a project might be “labour-based”, equipment-based material haulage is often the most expensive component of the total construction costs. The pie charts in Figure 2.1 illustrate typical expenditure patterns for sample roads from the Zambian Feeder Roads Project (FRP), Eastern Province, and some regravelling projects completed under the SIDA funded Minor Roads Project (MRP) contractor training programme in Central Province, Kenya.
The diagrams clearly indicate the importance of the haulage component in the final costs of labour-based road works. In addition, drainage structures and compaction will also involve some haulage equipment, in particular for transporting construction materials to site (culverts, cement, sand, aggregates, etc.) and for watering. The cost breakdown is based on contract documents prepared by Norconsult for the two projects. This analysis was simplified by the fact that Bills of Quantities were initially set up as bills summarising items according to their common input requirements as follows:

- Labour
- Equipment
- Materials

Table 2.1 provides further background information on road standards, equipment type, organisational set up and quantity of work for key items.
Table 2.1: Background data for sample projects

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>FRP, Eastern Province</th>
<th>MRP, Kenya, Zambia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of contracts</td>
<td>No.</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Total length of sample roads</td>
<td>km</td>
<td>43.2</td>
<td>24.6</td>
</tr>
<tr>
<td>Average width of carriageway</td>
<td>m</td>
<td>4.80</td>
<td>4.70</td>
</tr>
<tr>
<td>Earthwork quantities</td>
<td>m³ / km (in situ)</td>
<td>370</td>
<td>50</td>
</tr>
<tr>
<td>Side drain quantities</td>
<td>m³ / km (in situ)</td>
<td>710</td>
<td>350</td>
</tr>
<tr>
<td>Number of culvert lines installed</td>
<td>(lines / km)</td>
<td>1.7</td>
<td>4.1</td>
</tr>
<tr>
<td>Gavel volume</td>
<td>m³ / km (loose)</td>
<td>520</td>
<td>800</td>
</tr>
<tr>
<td>Total gravel haulage</td>
<td>m³ x km (loose)</td>
<td>38,300</td>
<td>206,300</td>
</tr>
<tr>
<td>Average gravel haulage distance</td>
<td>km</td>
<td>1.7</td>
<td>10.5</td>
</tr>
<tr>
<td>Contract award</td>
<td></td>
<td>fixed rate</td>
<td>selected tender</td>
</tr>
<tr>
<td>Haulage equipment</td>
<td></td>
<td>tractor / trailer</td>
<td>trucks</td>
</tr>
<tr>
<td>Equipment leased through project:</td>
<td>60 hp tractors</td>
<td>2</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>trailers 2.8 m³</td>
<td>3</td>
<td>none</td>
</tr>
<tr>
<td>Annual interest rate</td>
<td></td>
<td>12% (project)</td>
<td>25% (market)</td>
</tr>
<tr>
<td>Average total construction costs</td>
<td>US$ / km</td>
<td>8,700</td>
<td>17,900</td>
</tr>
<tr>
<td>Average exchange rate</td>
<td>Local cur/US$</td>
<td>1,300</td>
<td>58</td>
</tr>
<tr>
<td>Price level</td>
<td>year</td>
<td>1997</td>
<td>1995/6</td>
</tr>
</tbody>
</table>

3.1.3 History of Equipment Choice for Labour-based Rural Road works

3.1.3.1 Calculation of equipment hire rates

Many labour-based projects use a tractor-trailer combination to haul material, since this is considered to be the cheapest and most appropriate technology. Entire generations of labour-based practitioners, planners and project designers have raised little objection to this approach as it is very much in line with common donor policies.

These conclusions were predicated from a number of publications and studies which were conducted on the topic in the mid seventies/early eighties. The World Bank Guide for Labor-based Construction Programs, first published in 1983, gave some valuable information on the issue. Appendix G of the report provided a comprehensive method of calculating costs and can be considered to be one of the best guidelines available at the time.
The assumptions and work models employed by this method are recapitulated in brief below:

- Equipment cost calculation was done using methods developed for heavy earth moving plant. The procedure was based on a table format which contained a number of predetermined calculation factors. The final results were expressed as a “direct rate” or hourly usage charge and did not differentiate between fixed and operating cost. The method could be easily applied manually and did not require computer access.

- Depreciation, capital recovery, maintenance, repairs, fuel, lubricants, tyres, salvage value, road license and insurance were the components considered in establishing the rates.

- Assumptions, among others, included economic life expressed in 10,000 hours of total service, entire operating lives of 8-10 years depending on item and 1,000 - 1,250 hours average yearly availability.

- Overhead cost, sales taxes, VAT and profits on the other hand were not included in the World Bank cost calculation model.

- Most labour-based projects at that time were undertaken through government departments, parastatals or specially created force account units. Equipment owned and operated by governments directly, tends to be under-utilised, which subsequently results in high usage charges. Contributory factors to this low productivity could be one or several of the following:

  1. Equipment stays idle due to cash flow problems or bureaucratic procurement procedures resulting in fuel shortage, lack of spares, tyres etc;

  2. Poorly equipped, staffed and managed government workshops provide inadequate repair and maintenance services;

  3. Low civil service salaries result in poor staff motivation and quality of work;

  4. Multipurpose equipment, e.g. tipper and flatbed trucks are diverted to activities other than their intended use on labour-based projects.

The application of the World Bank calculation method resulted in hourly usage rates as shown in Table 3.1.
Table 3.1: Hourly usage rates (Price level 1976)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Specifications</th>
<th>Usage rate US$/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flatbed truck</td>
<td>6 m³ loading capacity</td>
<td>5.3</td>
</tr>
<tr>
<td>Tipper truck</td>
<td>6 m³ loading capacity</td>
<td>6.9</td>
</tr>
<tr>
<td>Tractor</td>
<td>35 hp</td>
<td>2.3</td>
</tr>
<tr>
<td>Tractor</td>
<td>50 hp</td>
<td>3.1</td>
</tr>
<tr>
<td>Tipping trailer</td>
<td>1 m³ loading capacity</td>
<td>0.5</td>
</tr>
<tr>
<td>Tipping trailer</td>
<td>3.5 m³ loading capacity</td>
<td>0.6</td>
</tr>
</tbody>
</table>

3.1.3.2 Calculation of haulage rates

Hourly usage rates alone are not sufficient for cost comparisons between different types of equipment. To achieve this, haulage rates are calculated by use of the following formula:

\[
\text{Haulage Rate} = \frac{A \times B \times C \times D \times E}{C \times D \times E} \text{ (US$/m² \times km)}
\]

Whereby:
- \(A\) = Hourly usage rate (US$/ hr)
- \(B\) = Number of working hours per day (hr/day)
- \(C\) = Average haulage distance (km)
- \(D\) = Loading capacity (m³/trip)
- \(E\) = Number of trips per day (trips/day)

However, haulage rate is not a constant value. Transportation of gravel over a distance of 1.0 km in 10 trips of 5 m³ each will be more expensive than if 5 m³ are to be moved in one trip over a distance of 10 km even though the total haulage of 50 m³xkm would in both cases be the same. For the latter, only one loading/unloading operation will be required while for the short 1.0 km distance the material is to be loaded/unloaded ten times, thus necessitating much longer equipment waiting periods.

Haulage rates presented in Figure 3.3.1 are calculated using the hire rates at price levels from 1976 as indicated in Table 3.1, and on productivity assumptions and daily target trips given in Table 3.2.1. and Table 3.2.2 below.
### Table 3.2.1: Equipment productivity assumption

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Loading time (min)</th>
<th>Haulage speed (km/hr)</th>
<th>Off-loading time (min)</th>
<th>Return speed (km/hr)</th>
<th>Working hours (hr/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flatbed truck</td>
<td>30</td>
<td>35</td>
<td>20</td>
<td>45</td>
<td>7</td>
</tr>
<tr>
<td>Tipper truck</td>
<td>36</td>
<td>35</td>
<td>5</td>
<td>45</td>
<td>7</td>
</tr>
<tr>
<td>Tractor 35 hp</td>
<td>5 a)</td>
<td>17.5</td>
<td>5</td>
<td>22.5</td>
<td>7</td>
</tr>
<tr>
<td>Tractor 50 hp</td>
<td>5 a)</td>
<td>20</td>
<td>5</td>
<td>25</td>
<td>7</td>
</tr>
</tbody>
</table>

It is assumed that tractors are equipped with two tipping trailers, so the time requirement only involves the change of trailers.

### Table 3.2.2: Daily target trips

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Daily target trips according to haulage distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (km)</td>
<td>&lt;1 1-2 2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10</td>
</tr>
<tr>
<td>Flatbed truck</td>
<td>8 8 7 7 7 6 6 6 5</td>
</tr>
<tr>
<td>Tipper truck</td>
<td>10 9 9 8 8 7 7 7 6</td>
</tr>
<tr>
<td>Tractor 35 hp</td>
<td>32 22 17 13 11 10 9 8 7</td>
</tr>
<tr>
<td>Tractor 50 hp</td>
<td>33 23 18 15 12 11 9 8 7</td>
</tr>
</tbody>
</table>

Cycle time = loading + haul distance + off-loading + haul distance haul speed return speed

Daily target trips = daily working hours cycle time

#### 3.1.3.3 Cost comparison of haulage rates between trucks and tractor / trailer combinations at 1976 price levels

Haulage rates were then calculated using the information and assumptions presented under sections 3.1 and 3.2. Comparison between different types of equipment is best illustrated in the format of a line diagram. Figure 3.3.1 provides haulage rates for flatbed trucks, tippers, 35hp and 50hp tractor/tipping-trailer combinations for haulage distances between < 1 and 10 km.
Figure 3.3.1: Haulage rates for distances < 1 to 10 km at 1976 price levels

<table>
<thead>
<tr>
<th>Equipment:</th>
<th>Flatbed truck</th>
<th>Tipper truck</th>
<th>35 hp tractor / 1m³ tipping-trailer</th>
<th>50 hp tractor / 3.5m³ tipping-trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD in km</td>
<td>(US$/m³xkm)</td>
<td>(US$/m³xkm)</td>
<td>(US$/m³xkm)</td>
<td>(US$/m³xkm)</td>
</tr>
<tr>
<td>0-1</td>
<td>1.52</td>
<td>1.63</td>
<td>1.44</td>
<td>0.52</td>
</tr>
<tr>
<td>1-2</td>
<td>0.54</td>
<td>0.58</td>
<td>0.70</td>
<td>0.25</td>
</tr>
<tr>
<td>2-3</td>
<td>0.34</td>
<td>0.37</td>
<td>0.56</td>
<td>0.19</td>
</tr>
<tr>
<td>3-4</td>
<td>0.26</td>
<td>0.28</td>
<td>0.49</td>
<td>0.17</td>
</tr>
<tr>
<td>4-5</td>
<td>0.21</td>
<td>0.23</td>
<td>0.46</td>
<td>0.16</td>
</tr>
<tr>
<td>5-6</td>
<td>0.18</td>
<td>0.20</td>
<td>0.44</td>
<td>0.15</td>
</tr>
<tr>
<td>6-7</td>
<td>0.16</td>
<td>0.18</td>
<td>0.42</td>
<td>0.14</td>
</tr>
<tr>
<td>7-8</td>
<td>0.14</td>
<td>0.16</td>
<td>0.41</td>
<td>0.14</td>
</tr>
<tr>
<td>8-9</td>
<td>0.13</td>
<td>0.15</td>
<td>0.40</td>
<td>0.13</td>
</tr>
<tr>
<td>9-10</td>
<td>0.12</td>
<td>0.14</td>
<td>0.39</td>
<td>0.13</td>
</tr>
</tbody>
</table>
The diagram, prepared on 1976 price levels and assumptions, confirms the following:

- The most economical option for material haulage up to a distance of about 5 km appeared to be a combination of one 50 hp tractor and two tipping trailers of 3.5 m³ loading capacity;
- No significant differences between haulage rates for tipper and flatbed trucks could be observed;
- Combinations of one 35 hp tractor and two 1.0 m³ tipping trailers were not economical;
- There was never a justifiable economical advantage of the tractor / trailer approach over trucks for haulage distances longer than 5 km.

3.1.4 Present Situation

New developments have undoubtedly taken place in the two decades since the previously mentioned studies were carried out. It should therefore be acceptable to look critically at various aspects of haulage equipment choice in order to find solutions which will include experiences from the past and reflect present situations in technical and economical terms.

3.1.4.1 Haulage equipment technology

Uniform standard specifications of tractor/trailer combinations suitable for labour-based roadworks do not exist. Information collected from various projects, however, shows that the most common type of equipment could be described as follow:

- 55-80 hp 2WD diesel engine powered agricultural tractors. A few projects are also using 4WD tractors with engines as large as 90 hp. The majority of models are fitted with hydraulic power steering, braking and hitching systems;
- Single axle non-tipping trailers of less than 3.0 m³ loading capacity. Tyres mostly of size used for 7-tonne trucks with a few models of balloon type or twin wheels;
- Purpose made gravel trailer designs including special heavy duty towing eyes and hitching systems;
- Flatbed or tipper trucks according to ordinary country specification. Loading capacity ranges from 5-6 m³ depending on make.

This summary reveals some significant differences from the assumptions made in the early studies in terms of:

- Higher powered tractor engines;
- More sophisticated tractor technologies;
- Smaller trailer size;
- Non-viability of tipping trailer systems;
- Lifetime of some trailer models shorter than anticipated;
- Need for purpose built trailer designs and hitching methods.

The reason for use of larger engine size tractors is not clearly established. It might be that the previously familiar 45 to 50 hp machines were not powerful enough for the intended purpose, which subsequently resulted in high running
costs due to frequent breakdowns. However, it is also to be considered that small engine sized agricultural equipment has become increasingly rare on local markets. A number of reputable tractor manufacturers offer their smallest models equipped with engines of 60 hp or more.

The need for limitation of trailer loading capacity to 3.0 m³, non-viability of tipping systems and requirement for special gravel trailer designs, including necessity for heavy duty pick up hitches, were all realised through more or less expensive trial and error processes.

In particular, it has to be emphasised that all attempts at utilising standard agricultural trailers have failed. Heavy duty gravel trailers are manufactured in local workshops and their procurement entails:

- Engineering design;
- Manufacture, testing and approval of prototype trailer;
- Preparation of detailed drawings and tender specifications;
- Quality control during mass production; and
- Final inspection and approval.

Procurement of gravel trailers is a time consuming undertaking compared with an “off the shelf” purchase of a truck or tractor. In most cases, these activities are the responsibility of highly qualified project staff. Acquisition of a small batch of trailers can amount to a substantial proportion of the actual manufacturing price. Expenses for procurement services are normally not added to the purchase price and therefore not reflected in the cost comparison between different haulage approaches.

3.1.4.2 Market environments

Economic viability of tractor / trailer haulage will always depend on availability and price levels for conventional road transport vehicles in a particular country. In the past, the alternatives were often restricted through low competition among truck suppliers. As recently as the mid eighties, a few manufacturers were holding more or less a monopoly in many countries. In an increasingly liberalised economy, these conditions are in the process of changing significantly.

These developments are best illustrated by comparison between equipment procurement cost per m³ of haulage capacity in 1976 and 1997. Indicative figures from Kenya, Zambia and the World Bank Guide reveal that costs for tractor/trailers have risen by 350%, while the price increase for trucks has only been about 260%.

In addition, it is essential that a comparison is made of the true value of the equipment. In many countries, different levels of import duties and sales taxes are applied for tractor/trailers and trucks. In 1995, for instance, the Ugandan Government charged 35% for trucks, while the rate for tractors was as low as 2% because the latter were classified as agricultural implements. Today, however, the contractors in the Uganda Transport Rehabilitation Project/Feeder Roads Component (UTRP/FRC) project will have to pay uniform rates of about 24% for all types of equipment. Choice of technology based on distorted market situations might not be sustainable and will have negative long term effects.
Use of equipment for operations other than the intended gravel haulage activities is another often brought up issue in the discussion about the choice of technology. General lack of road transport capacities is a common problem many government organisations are facing. Suitability of equipment for multipurpose road transportation might therefore not be desirable in a force account environment as it can easily lead to vehicle misuse.

It is questionable as to whether the same criteria should be applied to the private sector. Employment of small scale contractors at their full capacity is a situation no client can ever guarantee. It might therefore be a matter of the contractors’ economic survival to have alternative equipment utilisation opportunities in the event of discontinuity in labour-based roadworks.

3.1.4.3 Pricing method

During project work planning, review of equipment procurement tenders and preparation of contract documents, Norconsult was repeatedly faced with the task of establishing accurate equipment costing figures. Calculation methods had to consider that:

- pricing was to be done for a real market situation without equipment leasing support;
- projects were carried out during periods of exceptionally high currency exchange rate fluctuations.

The need for an efficient calculation procedure, allowing constant updating of price levels, was therefore evident. It was also realised that the objective could only be achieved by use of appropriate computer spreadsheet programs. The chosen approach was based on a separate estimation of fixed and operating costs:

<table>
<thead>
<tr>
<th>Fixed cost:</th>
<th>Operating cost:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest</td>
<td>Fuel</td>
</tr>
<tr>
<td>Depreciation</td>
<td>Lubricants</td>
</tr>
<tr>
<td>Road license and insurance</td>
<td>Maintenance and repairs</td>
</tr>
<tr>
<td>Drivers’ salary</td>
<td>Tyres</td>
</tr>
</tbody>
</table>

A key element in establishing reliable costing procedures is the identification and definition of parameters. Tractors are commonly equipped with hour clock meters while the mileage on trucks is normally measured in km. It is therefore essential to formulate all required inputs in the respective units for easy transfer from information provided by the manufacturer or which is to be collected from utilisation reports. In addition, we opted to express the productivity performance in relation to actual cycle times by assumption of:

- Loading time (or changing time for tractor / trailer combinations);
- Travel speed of loaded haulage equipment from quarry to dumping place;
- Off-loading time;
- Return speed of empty haulage equipment from dumping place to quarry.

The required data are to be logged in a single input entry sheet. An example of the chosen format appears in Table 4.3.1. Figures and prices contained in the sheet do not refer to a particular project, but they could be considered as a
realistic guideline of assumptions for counties including Uganda, Tanzania, Zambia and to some extent also Kenya.

Table 4.3.1 Data Log Sheet for Calculation of Haulage Rates

<table>
<thead>
<tr>
<th>BASIC EQUIPMENT PRICES</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of equipment</td>
<td>Truck</td>
<td>Tipping</td>
<td>applicable</td>
<td>x</td>
</tr>
<tr>
<td>(Truck or Tractor/Trailer)</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Breakdown of Equipment Purchase Prices</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Truck</td>
<td>Tractor</td>
<td>Trailer</td>
<td>Combination</td>
</tr>
<tr>
<td></td>
<td>Unit</td>
<td>Unit</td>
<td>Unit</td>
<td>Unit</td>
</tr>
<tr>
<td>Initial price per piece</td>
<td>45,000</td>
<td>19,000</td>
<td>5,000</td>
<td>29,000</td>
</tr>
<tr>
<td>US$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional costs for tipping and hitching mechanism</td>
<td>2,500</td>
<td>1,600</td>
<td>1,000</td>
<td>4,400</td>
</tr>
<tr>
<td>US$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shipment costs per piece (incl. clearing)</td>
<td>400</td>
<td>300</td>
<td>160</td>
<td>500</td>
</tr>
<tr>
<td>US$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duty in %</td>
<td>5.3%</td>
<td>5.3%</td>
<td>3.9%</td>
<td></td>
</tr>
<tr>
<td>(on initial price)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tax in %</td>
<td>18.7%</td>
<td>18.7%</td>
<td>19.8%</td>
<td></td>
</tr>
<tr>
<td>(on initial price)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cost of equipment *)</td>
<td>59,200</td>
<td>25,460</td>
<td>7,705</td>
<td>40,870</td>
</tr>
<tr>
<td>US$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of trailers per tractor</td>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel price</td>
<td>0.90</td>
<td>0.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>US$/litre</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lubricants</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(in % of fuel costs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MTCE &amp; Repair</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(in % of purchase price)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tyre purchase price</td>
<td>2,500</td>
<td>2,000</td>
<td>250</td>
<td>2,500</td>
</tr>
<tr>
<td>US$/litre</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tyre purchase price (rear)</td>
<td>250</td>
<td>900</td>
<td></td>
<td></td>
</tr>
<tr>
<td>US$/litre</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of tyres per piece</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>(front)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(rear)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total tyre cost per piece of equipment</td>
<td>1,500</td>
<td>2,200</td>
<td>500</td>
<td>3,200</td>
</tr>
<tr>
<td>US$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total equipment cost includes:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tractor</td>
<td>15%</td>
<td>15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overhead</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(commercial rate)</td>
<td>23.00%</td>
<td>23.00%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road licence &amp; insurance</td>
<td>6%</td>
<td>6.00%</td>
<td>6.00%</td>
<td>6.00%</td>
</tr>
<tr>
<td>% per year</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drivers &amp; turnboys' salary</td>
<td>200</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>US$/month</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salvage value of equipment in % of initial price</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>ASSUMED EQUIPMENT UTILISATION:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected life of equipment to value as above</td>
<td>200,000</td>
<td>10,000</td>
<td>10,000</td>
<td>variable</td>
</tr>
<tr>
<td>km</td>
<td>hours</td>
<td>hours</td>
<td>km</td>
<td></td>
</tr>
<tr>
<td>Unproductive mileage per day (trips to camp etc.)</td>
<td>25</td>
<td>1.00</td>
<td></td>
<td>variable</td>
</tr>
<tr>
<td>km per day</td>
<td>hours per day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Converted unproductive mileage per year</td>
<td>5,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>km</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability (equipment in use)</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Days / year</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. pay-back period (max. PBP)</td>
<td>10</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONSUMPTIONS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>32</td>
<td>5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit of fuel consumption</td>
<td>litre / 100 km</td>
<td>litre / hour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Converted fuel consumption</td>
<td>32</td>
<td></td>
<td>litre / 100 km</td>
<td></td>
</tr>
<tr>
<td>No. of tyres piece of equipment</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Tyre replacements</td>
<td>25,000</td>
<td>25,000</td>
<td>40,000</td>
<td>29,688</td>
</tr>
<tr>
<td>km</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loading capacity (loose gravel)</td>
<td>8,400</td>
<td></td>
<td>3,920</td>
<td></td>
</tr>
<tr>
<td>(by weight)</td>
<td>m3 / trip</td>
<td>kg / trip</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CYCLE TIMES &amp; PRODUCTIVITIES:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loading time</td>
<td>35</td>
<td>30</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haul speed</td>
<td>35</td>
<td>35</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>km / hour</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Off- loading time</td>
<td>5</td>
<td>24</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Return speed</td>
<td>45</td>
<td>45</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>km / hour</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working time</td>
<td>7.0</td>
<td>7.0</td>
<td>7.0</td>
<td>7.0</td>
</tr>
<tr>
<td>hours / day</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONTRACTOR ALLOWANCES:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overhead</td>
<td>15%</td>
<td>15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Profit</td>
<td>15%</td>
<td>15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total contractor allowance</td>
<td>30%</td>
<td>30%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*) Total equipment cost includes:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>initial price,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>additional cost (if applicable),</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>shipment costs, duty, tax,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>minus salvage value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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3.1.4.4 Cost comparison of haulage rates between trucks and tractor / trailer

Combinations at 1997 price levels

The data in Table 4.3.1 were the used in the preparation of an updated line diagram for haulage rates at current price levels as presented in Figure 4.4.1

Figure 4.4.1 Haulage rates for distances < 1 to 12 km at 1997 price level

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Flatbed truck 6.0 m³</th>
<th>Tipper truck 6.0 m³</th>
<th>Tractor 80 hp / Non-tipping trailers 2.8 m³</th>
<th>Tractor 80 hp / tipping trailers 2.8 m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD in km</td>
<td>(US$ / m³ km)</td>
<td>(US$ / m³ km)</td>
<td>(US$ / m³ km)</td>
<td>(US$ / m³ km)</td>
</tr>
<tr>
<td>0-1</td>
<td>6.21</td>
<td>4.97</td>
<td>5.22</td>
<td>2.73</td>
</tr>
<tr>
<td>1-2</td>
<td>2.34</td>
<td>1.94</td>
<td>2.31</td>
<td>1.52</td>
</tr>
<tr>
<td>2-3</td>
<td>1.58</td>
<td>1.35</td>
<td>1.74</td>
<td>1.28</td>
</tr>
<tr>
<td>3-4</td>
<td>1.26</td>
<td>1.10</td>
<td>1.49</td>
<td>1.19</td>
</tr>
<tr>
<td>4-5</td>
<td>1.08</td>
<td>0.97</td>
<td>1.36</td>
<td>1.13</td>
</tr>
<tr>
<td>5-6</td>
<td>0.98</td>
<td>0.89</td>
<td>1.28</td>
<td>1.10</td>
</tr>
<tr>
<td>6-7</td>
<td>0.90</td>
<td>0.84</td>
<td>1.22</td>
<td>1.08</td>
</tr>
<tr>
<td>7-8</td>
<td>0.85</td>
<td>0.80</td>
<td>1.18</td>
<td>1.07</td>
</tr>
<tr>
<td>8-9</td>
<td>0.82</td>
<td>0.77</td>
<td>1.15</td>
<td>1.05</td>
</tr>
<tr>
<td>9-10</td>
<td>0.79</td>
<td>0.75</td>
<td>1.12</td>
<td>1.05</td>
</tr>
<tr>
<td>10-11</td>
<td>0.76</td>
<td>0.73</td>
<td>1.10</td>
<td>1.04</td>
</tr>
<tr>
<td>11-12</td>
<td>0.74</td>
<td>0.71</td>
<td>1.09</td>
<td>1.03</td>
</tr>
</tbody>
</table>

Compared with the results presented in Figure 3.3.1, the updated diagram reveals a clear shift of competitiveness from tractor / trailers towards tipper and flatbed trucks.
3.1.4.5 Annual haulage capacities

The planner of a labour-based roadworks programme will, apart from selecting the most suitable type of haulage equipment, also have to decide on the size of required fleet. It is obvious that this conclusion will depend to a great extent on haulage distances prevailing in the project area. Figure 4.5.1 provides annual haulage capacities per piece of equipment based on the assumptions presented in the data log sheet in Table 4.3.1.

Figure 4.5.1: Annual haulage (in m$^3$/year)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Flatbed truck 6.0 m$^3$</th>
<th>Tipper truck 6.0 m$^3$</th>
<th>Tractor 80 hp / Non-tipping trailers 2.8 m$^3$</th>
<th>Tractor 80 hp / tipping trailers 2.8 m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD in km</td>
<td>(m$^3$/year)</td>
<td>(m$^3$/year)</td>
<td>(m$^3$/year)</td>
<td>(m$^3$/year)</td>
</tr>
<tr>
<td>0-1</td>
<td>9,077</td>
<td>11,852</td>
<td>8,491</td>
<td>18,520</td>
</tr>
<tr>
<td>1-2</td>
<td>8,605</td>
<td>11,060</td>
<td>7,106</td>
<td>12,994</td>
</tr>
<tr>
<td>2-3</td>
<td>8,179</td>
<td>10,366</td>
<td>6,109</td>
<td>10,099</td>
</tr>
<tr>
<td>3-4</td>
<td>7,794</td>
<td>9,755</td>
<td>5,358</td>
<td>8,138</td>
</tr>
<tr>
<td>4-5</td>
<td>7,443</td>
<td>9,211</td>
<td>4,771</td>
<td>6,857</td>
</tr>
<tr>
<td>5-6</td>
<td>7,122</td>
<td>8,725</td>
<td>4,300</td>
<td>5,924</td>
</tr>
<tr>
<td>6-7</td>
<td>6,828</td>
<td>8,288</td>
<td>3,913</td>
<td>5,215</td>
</tr>
<tr>
<td>7-8</td>
<td>6,558</td>
<td>7,893</td>
<td>3,591</td>
<td>4,657</td>
</tr>
<tr>
<td>8-9</td>
<td>6,308</td>
<td>7,533</td>
<td>3,317</td>
<td>4,208</td>
</tr>
<tr>
<td>9-10</td>
<td>6,076</td>
<td>7,205</td>
<td>3,043</td>
<td>3,837</td>
</tr>
<tr>
<td>10-11</td>
<td>5,860</td>
<td>6,904</td>
<td>2,879</td>
<td>3,526</td>
</tr>
<tr>
<td>11-12</td>
<td>5,660</td>
<td>6,627</td>
<td>2,700</td>
<td>3,262</td>
</tr>
</tbody>
</table>
3.1.5 Conclusions and Recommendations

The above analyses of developments in haulage technologies for labour-based road works have been drawn together below to form a number of conclusions and recommendations for future project planning:

- Analysis of technical options, work organisation and development of price levels over the past 20 years reveals that some significant changes have taken place over this period. Additional conditions might also vary from country to country. An independent assessment of the prevailing situation is considered an essential task to be undertaken during the project planning stage and should include:
  - Equipment investment cost (broken down in initial charges, shipment and clearing, taxes and duty);
  - Basic prices relevant for the establishment of equipment operating costs e.g., fuel, lubricants and tyres;
  - Assessment of expected haulage distances to be established through gravel surveys in case information on material availability in area is inadequate;
  - Comparison of haulage rates between different types priced on actual project conditions.

- Use of computer spreadsheet programmes for calculation of haulage rates is recommended and is best achieved by separation of the three main cost components:
  - Fixed cost;
  - Operating cost;
  - Overhead and profit.

- Calculation should be based on actual equipment running times according to haulage distance rather than on estimated annual average utilisation. Cost parameters are to be expressed in a format which allows easy reference to manufacturers’ technical data and performance reports.

- Conclusions made on choice of haulage equipment may reflect the present situation in Uganda, Tanzania, Kenya and Zambia and can be summarised in brief as follows:
  - Early studies indicated an economic viability of material haulage by tractor / tipping trailer combinations up to a haulage distance of about 5 - 6 km;
  - Review of costing methods and assumptions considering developments over the last 20 years revealed almost equal costs for haulage by trucks and tractor / non-tipping trailer combinations over distances < 2.5 km, while trucks appear to be 50% more economical for transports over a distance of more than 12 km;
  - There is little evidence of successful use of tipping trailers. The method is therefore considered as not viable.
• The highest possible output per equipment unit is achievable by 7 - 8 tonne tipper trucks. Performance of flatbed or tractor / non-tipping trailer combinations ranges from 40% to 80% of the tipper capacities.

Abbreviations

MRP          Minor Roads Programme
FRP          Feeder Roads Project
SIDA         Swedish International Development Co-operation Agency
UTRP/FRC     Uganda Transport Rehabilitation Project / Feeder Roads Component
References


3.2 EQUIPMENT FOR THE DNEP/DFID FEEDER ROADS PROJECT, MOZAMBIQUE

R N Geddes, (Project Advisor, DNEP/DFID Feeder Roads Project, Zambézia, Mozambique)

Synopsis

This paper provides a general account of the equipment ordered for the DNEP/DFID Feeder Roads Project in Zambézia Province, Mozambique, and comments on the adequacy and performance of specific items in the early stages of the project. An outline is provided of the procurement process, and the measures taken for clearing the equipment through Mozambique customs. Specific details of the tractor/trailer combinations, and the choice of compaction equipment, are discussed.

The objectives of the project include the rehabilitation of tertiary roads in Zambézia Province, in order to improve the economic and social prosperity of the local population, and the development of capacity in the local road construction industry. Implementation of the works is by emergent, small-scale local contractors who are receiving training within the project.

The project is relatively equipment intensive compared with other labour-based projects, and equipment costs account for about 25% of the cost of the rehabilitated roads. The bulk of the equipment has been provided for gravelling operations and for compaction. This is appropriate considering the amount of gravelling that will be required, and the generally poor quality of the in situ soils. Adequate compaction at the roadbed preparation and formation stages is essential.

An important aspect of the motivation and development of the contractors is the opportunity to own equipment, and the project provides for the transfer of ownership to the contractors.

The paper focuses on the primary equipment supplied for use on the sites and does not include details of hand tools, mechanical workshop tools, survey equipment, radios, computers, office supplies and equipment, carpentry tools, air-conditioners and stand-by generators also supplied to the project.

The description of faults and inadequacies of some items is not meant as criticism of the suppliers, since the equipment is not necessary specifically designed for use in labour-based road construction in remote areas of Africa. The comments are provided to assist those specifying equipment for similar projects in the future to predict and avoid similar problems.

3.2.1 Background to the Project

The purpose of the DNEP/DFID Feeder Roads Project is to rehabilitate approximately 800km of existing classified feeder roads in Zambézia Province,
Mozambique, in order to improve the economic and social well being of the local population. The project is being implemented by the Mozambique National Directorate of Roads and Bridges (DNEP) through DEP Zambézia, the Provincial Department of Roads and Bridges. Support to DNEP and DEP for the management of the project is being provided by consultants.

The project is being funded by the British Government, through the Department for International Development (DFID), for the purchase of equipment, materials, works execution and payment to consultants. In addition, DFID are funding upgrading of accommodation, some road maintenance (within the project period) and UK/regional training. The Government of Mozambique contribution includes the payment of import duties, DEP supervision of the works, offices and housing for the Consultants, and in-country training.

The project is part of DNEP’s Feeder Roads Programme, which in turn is part of the World Bank-supported Roads and Coastal Shipping Project (ROCS) which seeks to ultimately rehabilitate the bulk of the road network in Mozambique.

An important objective of the project is to develop local capacity for the implementation of rehabilitation and maintenance works by local private contractors using labour-based methods. To this extent, the project is unique within the Feeder Roads Programme, which traditionally operates direct labour brigades through the provincial ECMEPs (state owned Enterprise for the Construction and Maintenance of Roads and Bridges).

Preparations for the implementation of the project started in September 1995 in order to facilitate the commencement of site operations after the 1995-1996 rains. The project completion date is 15 September 2000.

The selection of contractors to participate in the project was made by the DNEP on the basis of recommendations from the Provincial Directorate of Works (DPOPH). The criteria used to select the contractors included: experience in construction; the calibre of staff employed; equipment already owned; financial status and perceived entrepreneurial ability.

By the end of July 1997, approximately 60 kilometres of road had been rehabilitated to all-weather standard and 40 kilometres were under routine maintenance. Six contractors are currently working independently on different sites in Mocuba and Ilé districts under the supervision of the Provincial Department of Roads and Bridges (DEP), and with continued support from the consultants. The roads are being rehabilitated to all-weather standard and significant lengths are being gravelled due to the poor quality of the in situ soils, which are fine grained and, in sandy areas, highly erodible. In non-sandy areas, spot-gravelling is being carried out on steep slopes and on stretches of particularly high plasticity. It is anticipated that up to 50% of the total length of road rehabilitated will require gravelling.

3.2.2 The Equipment List

The list of equipment prepared for the project was based on the standard equipment list for the Feeder Roads Programme brigades. Details of the principal items and comments on their performance and suitability are given in Appendix A.
The quantity of items required was calculated on the assumption that some contractors would develop larger operations than others, and would therefore require, and be able to afford, more equipment. The full purchase price of the equipment, including transport and import duties, was used in the derivation of rental and hire-purchase rates. Since these costs are significant, representing about one-quarter of the average monthly turn-over, the contractors are discouraged from having idle or under-utilised plant on site.

The contractors will be encouraged to purchase equipment in accordance with their management capacity in order to avoid over-capitalisation through the purchase of assets that may be surplus to their requirements. Future work opportunities, beyond the end of the project, will likely be confined to routine maintenance contracts.

Items of equipment that are not purchased by contractors will be kept centrally and will be available for hire for the duration of the project. At the end of the project, DNEP will either dispose of the surplus equipment or continue to make it available for hire.

The unit rates used for the valuation of the contractor’s work are derived using the full purchase price of the equipment. The contractors are therefore in a position to seek alternative, and possibly cheaper sources of equipment. This approach is being encouraged as it promotes self-reliance and allows the contractors to maximise their profitability. One contractor has already purchased a new tractor/trailer combination from the local Massey Ferguson agent, and others are rehabilitating old tractors for deployment on site. A 10 tonne flat-bed truck, owned by one of the contractors, has been used in gravelling operations in tandem with tractor/trailer combinations to boost output over long haul distances.

### 3.2.3 Procurement of Equipment

The procurement of equipment for use on the project is being done by the consultants through an associated company. The payment of import duty for the clearance of the goods is the responsibility of the Government of Mozambique through the DNEP, who are the owners of the equipment.

The equipment has been ordered in two main consignments in order to reduce the risk of over-supply in the event that it would not be possible to find enough contractors to participate in the project.

The equipment list was prepared by the consultants on the basis of the requirements of the Project Appraisal and was approved by DNEP and DFID in February 1996. The first orders were placed in May 1996 and most of the equipment from the first consignment was operational on site before the end of 1996. The preparation of documentation for the importation of some items, such as the mechanic tools and equipment, was delayed in Mozambique due to the large number of items, and the complexity of the descriptions of the goods, which had to be translated into Portuguese.

To date, all items for the first consignment have been received in the port of Quelimane and have been cleared through customs for use on site. The ordering and delivery of items from the second consignment has commenced, in
accordance with the site requirements, and some items from the second consignment have been received.

The importation and clearance of the equipment has been initiated and managed on behalf of DNEP by the consultant's project team based in Quelimane. The key to the success of this involvement has been the local recruitment of a Mozambican administrator with a thorough knowledge of Quelimane, and some experience in dealing with the various agencies involved in the process of importation. The decision to manage the process at a local level has been critical to its success, since most of the equipment has been delivered directly to the port of Quelimane, some 1,600km from Maputo.

DNEP’s involvement has included arrangements for the payment of customs duties by the Ministry of Finance. DNEP’s capacity for dealing with large consignments of imported equipment is now well developed following many years of experience, and the clearance of the goods has been relatively trouble-free.

Project funds have been used for the payment for services provided in Quelimane, such as the production of the import permits, port charges, and the licensing and insuring of equipment following customs clearance. This has been a considerable advantage in reducing delays in the deployment of equipment on the sites.

3.2.4 Expenditure

The total expenditure on equipment to date is slightly less than US$2,400,000, which represents about 74% of the budget provided. A further US$300,000 has been committed in orders for the second consignment. The equipment budget represents about one-quarter of the total project budget.

3.2.5 Equipment Use and Maintenance

The equipment is owned by the DNEP who hire it to the contractors. The hire rates have been calculated to reflect the true cost of owning and operating equipment and include interest at a rate of 12% per annum. Payments are made by the contractors as deductions from their monthly certificates.

The Project allows for the contractors to purchase items of equipment in accordance with their requirements. DNEP are currently preparing proposals to the Ministry of Finance for a hire purchase contract. This will enable DNEP to transfer ownership to the contractors through a series of hire purchase payments made over an appropriate time period agreed by both parties.

Management of the equipment is the responsibility of the DEP Plant Manager who is the counterpart to the consultant's Mechanical Technician. The Plant Manager produces monthly invoices to each contractor for equipment hired during the month.

Maintenance and repairs to the equipment are undertaken by mechanics employed by the contractors with support and training from the consultant's Mechanical Technician. Additional training is being provided by DNEP through training courses held at the Training Centre in Chimoio.
3.2.6 Specific Comments About Tractor/Trailer Combinations and Compaction

3.2.6.1 Tractor/trailer combinations

Labour-based works in Mozambique within the Feeder Roads Programme (FRP) have been carried out using Massey Ferguson 240 (52HP) tractors for several years and it was decided that MF240s should provide the bulk of the tractors ordered for this project. FRP brigades are also equipped with a four-wheel drive MF 390 (85 HP) tractor which is used primarily to spread excavated material from the side-drains, in the construction of the formation, using Arthur Garden towed graders from Zimbabwe.

At the project inception, it was decided that spreading would be done as an entirely labour-based activity, without the use of a towed grader, so it was deemed unnecessary to provide 85 HP, four-wheel drive tractors. Nevertheless, it was recognised that additional power might be required for certain tasks: e.g. towing the water bowers out of deep river valleys, and MF275 (70HP) tractors were included on the equipment list.

The tractor order is designed to equip each contractor with one MF275 tractor and up to four MF240 tractors for large-scale gravelling works. Contractors not undertaking gravelling find one MF275 tractor to be adequate to deal with daily site transport requirements.

Experience to date indicates that the MF 240s have sufficient power for most site activities, but severe problems have been experienced on site with failure to the tow hitches.

The design of the 3m³ Herculano trailer, with 20 inch wheels located towards the rear of the trailer, results in the transfer of excessive weight to the tractor and has resulted in the shearing of the bolts fixing the tow-hitch to the tractor chassis. In some cases the tow-hitch has broken. This problem is common to Feeder Roads Programme operations in Mozambique.

The following measures are under consideration to remedy the situation:
- Modify the trailers to reduce their capacity and to move the centre of gravity of the load further towards the rear of the trailer.
- Move the trailer axle forward to reduce the load applied to the tow hitch.
- Install heavy duty tow-hitches (“Natal Hitch”).
- Provide smaller diameter wheels to reduce the inclination of the trailer draw-bar onto the tractor tow-hitch.
- Encourage the contractors to provide easier access from the borrow pits in order to reduce the dynamic stresses on the tow-hitches.

3.2.6.2 Compaction

The decision to use equipment for compaction was made at the time of the project inception on the basis that equipment is generally used for compaction by Feeder Roads Programme brigades, and in order to achieve the planned output of rehabilitated road. The following equipment has been supplied to facilitate this:
- Towed 2,275 litre water bowers with spray-bars,
• Water pumps,
• Pedestrian rollers,
• Towed rollers,
• Additional tractors.

The decision to provide towed rollers was based on experience that has shown pedestrian rollers to be unreliable in the long-term in remote areas where service back-up facilities are not available. It was anticipated that towed rollers would provide the contractors with compaction capability well into the future, even if the vibrating mechanisms on the rollers were no longer functional. The supply of a pedestrian and a towed roller to the sites provides the contractors with the capacity to undertake formation and gravelling works simultaneously.

The attainment of optimum moisture content is essential to ensure that compaction is achieved. The water pumps and bowser are therefore a key factor in the site operations if maximum output is to be achieved by the towed rollers. This is particularly important in the construction of the road-bed and the formation.

The total cost of the equipment provided for the compaction will be approximately US$650,000. The cost per kilometre of fully gravelled road, in terms of the hire rates and operating costs, is about US$1,500. The towed rollers are particularly expensive items.

IBIS, a Danish NGO operating in Zambézia, has been able to achieve reasonable levels of compaction using hand-pulled dead-weight rollers fabricated locally. Water is collected by tractor and trailer in drums which are filled by hand with buckets from the nearest river. The water is spread on the road with watering cans. This method is clearly much cheaper than methods employing mechanical equipment for watering and compaction but produces low output if optimum moisture content is to be guaranteed. The roads rehabilitated by IBIS are generally in areas of good soils, and relatively little gravelling has been undertaken.

The alternative approach of simply allowing traffic to facilitate compaction is not considered appropriate in Zambézia, because the traffic levels on most tertiary roads are very low, particularly during construction when the road may be impassable farther along.

3.2.7 Conclusion

The equipment specifications and quantities for the DNEP/DFID Feeder Roads Project have been designed to enable the project to attain its objectives in terms of output of rehabilitated road and the development of capacity within the local road contractor industry. The equipment specified is largely similar to equipment supplied to brigades within the national Feeder Roads Programme, but the quantities have been adjusted to meet the requirements of private contractors.

The decision to utilise relatively large amounts of equipment on the project is justified on the basis that high outputs of completed road are required, and that there will be a high proportion of gravelling.
Bureaucratic delays in the ordering and delivery of equipment to the sites have largely been overcome through prompt payment of import duties by the DNEP, and proactive support by the consultants for the management of the process. The availability of project funds at a provincial level has been significant in facilitating the movement of goods through Quelimane port and on to the sites.

The equipment is owned by DNEP who lease it to the contractors at rates that reflect the full purchase price. The contractors will ultimately have the opportunity to purchase items of equipment from DNEP on the basis of a lease-hire agreement. The opportunity to own equipment is a major motivator for the contractors, and provides them with a means to invest in capital assets, which is essential for the growth of a small business.

Most of the equipment has operated relatively trouble free in the early phase of the project and the most significant problem faced to date has been the failure of the tow hitches on the MF240 tractors, which are inadequate to support the applied loading from the Herculano trailers when fully laden with gravel. Various measures are under consideration to remedy this situation. Modifications are also required to the fuel filter configuration on the Lister engines supplied with the Benford rollers.

Preventative maintenance systems are in place, and mechanics employed by the contractors are undertaking the majority of the maintenance and repairs under the supervision and control of the Mechanical Technician employed by the Consultant.

It is anticipated that future studies of the equipment supplied to the project will provide additional insights into the long term durability of specific items. Interesting comparisons, such as the differences in operation of the Herculano and Tinto trailers, will be made. Further analysis will also detail the set of equipment finally purchased by each contractor, and how this equipment contributes to their business development.
## Appendix A: Equipment Specifications

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Comments on performance</th>
<th>Approximate cost CIF Quelimane including import duty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractors</td>
<td>Massey Ferguson MF240S 2 wheel-drive tractor Perkins 3 cylinder A3/152S engine 52 Horse Power</td>
<td>Generally sufficient power for most tasks. Unable to pull the towed roller up steep gradients. The tow hitch is inadequate for the loads applied by the trailers, and virtually all have broken at least once. The indicator switches are of poor quality and break easily. A maximum of 6x27kg front weights should be carried to prevent the weight frame from breaking. The bolts fixing the tow hitch and front weight frame should be tightened daily.</td>
<td>$18,300</td>
</tr>
<tr>
<td></td>
<td>Massey Ferguson MF275 2 wheel drive tractor Perkins 4 cylinder A4-236 engine, 70 Horse Power</td>
<td>Sufficient power for all operations but is unable to pull the towed roller up steep gradients. The indicator switches are of poor quality and break easily. The oil bath air filters provided are easier and cheaper to maintain than the paper element filters supplied with the MF240s but may be less effective in cleaning the air drawn into the engine.</td>
<td>$23,900</td>
</tr>
<tr>
<td>Trailers</td>
<td>Herculano heavy duty, non-tipping trailer 5 tonne (3m³) capacity, 20&quot; wheels</td>
<td>The trailers are generally poorly finished. The chassis is weak in the draw-bar area. Reinforcement of trailer chassis is ongoing on site. The jack stand mechanism is inadequate and breaks easily. Too much load is transferred to the tractor resulting in broken tow hitches.</td>
<td>$4,200</td>
</tr>
<tr>
<td></td>
<td>Tinto heavy duty, non-tipping trailer 5 tonne (3m³) capacity, 20&quot; wheels</td>
<td>Not yet operational on site.</td>
<td>$6,000</td>
</tr>
<tr>
<td>Towed fuel</td>
<td>3884 litre single axle bowser. Steel tank with rotary discharge hand pump complete with flow metre.</td>
<td>No specific problems have been encountered. The jack is well designed and no failures have been experienced.</td>
<td>$7,300</td>
</tr>
<tr>
<td>Equipment Type</td>
<td>Description</td>
<td>Problems / Observations</td>
<td>Cost</td>
</tr>
<tr>
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<tr>
<td>Towed water bowser(s)</td>
<td>2275 litre single axle bowser. Steel tank, gravity fed dribble spray bar</td>
<td>It has been necessary to enlarge and increase the number of holes in the spray bars.</td>
<td>$5,600</td>
</tr>
<tr>
<td></td>
<td>1137 litre single axle bowser. Steel tank.</td>
<td>No specific problems have been encountered.</td>
<td>$4,200</td>
</tr>
<tr>
<td>Towed rollers</td>
<td>PÔMA AH150 PTO driven vibratory roller. Total weight 2.8 tonnes</td>
<td>Little experience has been gained to date since the rollers were recently supplied.</td>
<td>$42,900</td>
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<td></td>
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<td>On steep gradients a 4-wheel-drive tractor is required or the compaction must be done</td>
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<td></td>
<td></td>
<td>with the pedestrian roller. The drive shaft from the PTO must be maintained (greased</td>
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<td></td>
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<td>approximately every 3 hours of work).</td>
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<tr>
<td>Pedestrian roller</td>
<td>Benford 2-75B double-drum pedestrian controlled vibratory roller. Lister/Petter</td>
<td>The engine configuration is apparently unable to cope with vibration of the roller</td>
<td>$9,500</td>
</tr>
<tr>
<td></td>
<td>TS1 single cylinder diesel engine. Operating weight 960kg, roll width 760mm</td>
<td>resulting in split fuel tanks. This will be remedied by remounting the tanks on</td>
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<td>flexible mountings. The standard fuel filter mounted inside the fuel tank is too</td>
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<td>small and breaks easily with vibration of the roller, resulting in dirty fuel</td>
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<td>entering the injectors. An alternative fuel filter configuration will be fitted by</td>
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<td></td>
<td>the supplier's South African agent shortly. Regular preventative maintenance to</td>
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<td></td>
<td></td>
<td>grease the vibrating mechanisms is essential.</td>
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</tr>
<tr>
<td>Supervision vehicles</td>
<td>Land Rover Defender Pick-up. 300 Tdi engine, 380 gearbox.</td>
<td>The Land Rover Tdi pick-up is regarded as the appropriate vehicle under the project</td>
<td>$32,200</td>
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<tr>
<td></td>
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<td>conditions. The full-time 4-wheel drive and coil spring suspension provide relative</td>
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<tr>
<td></td>
<td></td>
<td>comfort and safety. Regular replacement of shock absorbers and brake pads has been</td>
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<tr>
<td></td>
<td></td>
<td>necessary due to very poor road conditions and the poor quality of standard Land</td>
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<tr>
<td></td>
<td></td>
<td>Rover spare parts supplied (i.e. shock absorbers and brake pads). Regular maintenance</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>of items such as door locks is essential.</td>
<td></td>
</tr>
<tr>
<td>Cargo trucks</td>
<td>Leyland Daf Comet 12.13 7 tonne flat-bed truck</td>
<td>It is considered that the trucks specified are probably too small and that a 10</td>
<td>$64,000</td>
</tr>
<tr>
<td></td>
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<td>tonne capacity truck would provide better ground clearance and higher loads on the</td>
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<td></td>
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<td>poor roads. The “Hiab” crane fitted to one flat-bed truck has proved invaluable for</td>
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<td></td>
<td></td>
<td>loading goods. The injector pump and injectors are very sensitive to dirty fuel.</td>
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<tr>
<td></td>
<td></td>
<td>The tachometers supplied with the trucks have proved invaluable to control the</td>
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<tr>
<td></td>
<td></td>
<td>operation of the trucks.</td>
<td></td>
</tr>
<tr>
<td>Device</td>
<td>Specification</td>
<td>Observations and Notes</td>
<td>Price</td>
</tr>
<tr>
<td>--------------------------------</td>
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</tr>
<tr>
<td>Self-propelled Diesel bowser</td>
<td>Leyland Daf Comet 12.13 7000 litre Whale diesel tanker</td>
<td>The bowser has been set up for European conditions which in some circumstances has proved inappropriate: e.g. the exhaust silencer is mounted underneath the engine at the front of the vehicle, between the wheels, and is thus vulnerable to damage from pot-holes. The vehicle was not waxed or well prepared for shipping and sea-air has caused corrosion in the electrical system resulting in failure of the tachometer and the pump safety switch. Corrosion has also occurred inside the tank and to the seal around the measuring stick.</td>
<td>$81,000</td>
</tr>
<tr>
<td>Water pump</td>
<td>SLD Model SEP50 2&quot;x 2&quot; self-priming portable pump. Lister Petter AC1 engine.</td>
<td>Max. capacity 500 litres per minute, max. delivery head 16m. No problems have been experienced.</td>
<td>$2,800</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>Yamaha DT125-3TT3</td>
<td>Several minor accidents have occurred, mainly due to the poor roads. The size of the motorcycles is considered appropriate but it may be preferable to provide a single seat to prevent the carrying of a passenger. Damage has been caused to the rear wheel rim when passing through deep pot-holes on surfaced roads with a passenger.</td>
<td>$3,200</td>
</tr>
<tr>
<td>Concrete mixers</td>
<td>Winget 175T tiling drum 240/175 concrete mixer. Lister Petter LT1 diesel engine.</td>
<td>Damage has been caused through a Contractor trying to tow the mixer behind a vehicle.</td>
<td>$4,200</td>
</tr>
<tr>
<td>Poker vibrators</td>
<td>FRP55 pendulum poker. HD10 Lister Petter AC1 diesel engine.</td>
<td>No problems to date but little site experience</td>
<td>$2,000</td>
</tr>
<tr>
<td>Rock breaking equipment</td>
<td>Ingersol Rand portable compressor P130/WD/G. Ingersol Rand Promaxx Breaker MX60. Ingersol Rand JH40 Jackhammer.</td>
<td>No problems to date but little site experience Specific training and supervision is required of the operators</td>
<td>$21,800</td>
</tr>
</tbody>
</table>
3.3 DEVELOPMENT OF AN APPROACH TO THE APPRAISAL OF TOOLS AND EQUIPMENT FOR LABOUR-BASED TECHNOLOGY IN ROAD WORKS: EXPERIENCE IN TANZANIA

Dr. P. F. C. Komba, Chief Engineer Rural Roads, Ministry of Works, Tanzania and L. M. Kyombo, Senior Engineer, Appropriate Technology Unit (ATU), Ministry of Works, Tanzania

Abstract

Labour based technology (LBT) in roads construction, rehabilitation and maintenance has been practised in Tanzania for more than 18 years. Nearly half of the country has implemented LBT in road works but acceptance and awareness levels are still low, despite of several efforts to promote the technology. Development of the technology at a national level has proved to have substantial social and economic benefits. However, the expansion of this technology at a national level should be accompanied by quantification of potential inputs which include labour, tools and equipment at a sustainable level.

Efforts to promote of the technology in Tanzania have revealed quite a number of deficiencies such as monitoring of quality of tools and corresponding performance, cost analysis for tools and equipment and monitoring of operational inputs and output levels including their optimisation. Coupled with this, performance data recording and keeping and co-ordination between implementers and local tools manufacturers is required for quality improvement and sustainability. Equipment consumes a significant portion (about 40%) of project costs but implementers have limited knowledge including guidelines on selection and costing as well as, logical approach towards optimisation of labour and equipment inputs for construction output. The investigations conducted in Tanzania have revealed that 7 tonne tipper trucks deployed for haulage are a possible alternative among common LBT haulage equipment.

The investigation has also developed logical relations on selection criteria and costing approaches and has recommended these for use as a basis for improvement of existing guidelines and establishment of checklists. Further studies are needed on the establishment of optimisation of labour and equipment operations to enhance competitive performance of different types of equipment for haulage in labour based technology.
3.3.1 Introduction

3.3.1.1 Background

Tanzania is one of the developing countries located in sub-Saharan Africa. It is a large country covering an area of 883,749 km² with an estimated population of 25.6 million, the majority live in rural areas. The economy is based on agriculture with most of the country’s rural population subsisting on farming.

Like many other developing countries, Tanzania is faced with development challenges, being poor and unable to afford full use of sophisticated equipment, it requires a more appropriate technology which will make use of locally available and abundant resources to improve the recorded income, social service delivery and provision of infrastructure services such as roads. This is necessary to contribute to the improvement of the rural economies and the quality of life.

Labour based technology involves the use of working systems that optimise the labour content through a cost-effective combination with the right tools and intermediate equipment. Efforts to promote LBT in road works in Tanzania have been made for more than half of the country and the technology is very much needed for quite a bigger portion of the country. In execution of the Integrated Roads Programme (IRP), the government decided to maximise the use of local resources and hence encouraged an introduction and expansion of the use of LBT wherever feasible. To promote the deployment of LBT, an institution dealing with LBT issues was established in 1993, referred to as the Appropriate Technology Unit (ATU). The unit is responsible for provision of advisory role to roadworks implementers targeting adoption of LBT on a large scale, appraisal of its feasibility, sustainability and replicability in the Tanzanian local environment. Key parameters being examined include institutional, managerial and administration considerations; as well as, the cost-effectiveness of the technology with emphasis that even if it might not be financially competitive it may be justified on socio-economic grounds.

Labourers are considered as the main means of production in LBT whereas to enable them to work efficiently and effectively, they need to be provided with proper and adequate tools among other things. The quality of tools is important for productivity as well as for safety. Significant effort should be devoted to the selection of the right tools in respect of the cost involved in order to safeguard labourer productivity and working environment.

LBT deployment in road projects requires attention if efficiency and a satisfactory final quality product are to be achieved. Intervention of labour operations in some tasks such as haulage and placing of road materials is required and provision of equipment of the right type and size, with clear timing and performance, require tactful organisation.

In Tanzania, studied projects executed using LBT, have revealed that about 35% to 45% of total cost is spent on tools and equipment as shown in Table 1.1.
Table 1.1: Labour-based technology roadworks project costs distribution experienced in five regions in Tanzania

<table>
<thead>
<tr>
<th>Activity</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mbeya</td>
</tr>
<tr>
<td>Labour + support staff</td>
<td>36.9%</td>
</tr>
<tr>
<td>Tools + equipment</td>
<td>36.3%</td>
</tr>
<tr>
<td>Materials + others</td>
<td>26.8%</td>
</tr>
</tbody>
</table>


In the selection of alternative strategies for road implementation, planners need to have data on availability and utilisation of machines, costs and achievable productivity. Project managers/implementers need to keep data on the right type of tools and equipment in relation to particular site conditions and environment. Together with that, proper assessment of performance of labourers and equipment, including analysis of constraints which affect their performance, is necessary.

The question of deployed tools and equipment appears to be simple, however, their design and quality have big influence on project costs. Selection/choice, costing and management of the same in the application of Labour-based techniques are aspects which can assist to ascertain products of appropriate and good quality. Also, they contribute to actual projects unit costs of works, potentiality of technology sustainability and determine profit margins of the contractors involved in these works.

3.3.1.2 Objectives

This paper attempts to address four main objectives. Firstly, to develop a general: logical framework on how to select and specify tools; a logical sequential approach to costing requirements for tools and equipment; and to evaluate management aspects with respect to tools and equipment basing on the experience gained from projects executed in Tanzania. Secondly, to evaluate the practice in the use of tools and equipment in respect of selection and management. Thirdly, to assess the impact of mixing labour and equipment operations with the aim of attaining optimum level of labour and equipment input for efficient construction output. Finally, to outline factors that affect proper selection, costing and management of tools and equipment in deploying LBT and suggest possible mitigation measures basing on Tanzanian conditions.
3.3.1.3 Methodology

The findings in this paper are based on the observations and field work done, which included literature review, site visits and interviews on LBT in roadwork practice, tools and equipment deployed, their standard, choice, costing and management aspects.

The study was restricted to observations on use of common general list of tools and equipment for key rehabilitation and maintenance activities. The list of activities, tools and equipment taken into consideration are shown in Table 1.2.

Table 1.2: List of activities, tools and equipment considered

<table>
<thead>
<tr>
<th>Activities</th>
<th>Tools</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavations of fill material and gravel</td>
<td>Pickaxe and mattock</td>
<td>Tipper truck</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7tonne)</td>
</tr>
<tr>
<td>Road forming up</td>
<td>Hoe, Forked Shovel and Spade</td>
<td>Towed grader</td>
</tr>
<tr>
<td>Ditching</td>
<td>Rake and Spreader</td>
<td>Water bowser</td>
</tr>
<tr>
<td>Haulage of gravel and fill material</td>
<td>Earth Rammer</td>
<td>Tractor and Trailer</td>
</tr>
<tr>
<td>Loading of gravel and fill material</td>
<td>Wheelbarrow</td>
<td></td>
</tr>
<tr>
<td>Spreading of gravel and fill material</td>
<td></td>
<td>Roller</td>
</tr>
<tr>
<td>Compaction</td>
<td></td>
<td>Slashers and grass cutters</td>
</tr>
<tr>
<td>Vegetation Control</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Based on practical experience, assumption of requirements for projects planning inputs and outputs, a certain sequential approach has been developed by the authors (Figure 1). Practitioners can utilise it as a check list on how to develop logical data inputs required at different implementation levels. Also, it can be the basis of control and monitoring of inputs during implementation. Costing of inputs such as, labour, tools, materials and equipment was one of the key aspects covered in this approach.

3.3.2 Selection/Choice of Tools and Equipment

To a great extent, tools and simple or intermediate items of equipment suitably selected for appropriate combination with labour, determine the quality that can be achieved.

In LBT planning and logistics, special emphasis should be put on information on quantity and type of resources for different sites and tasks. Tools, equipment and labour productivity and availability contributes to the selection of optimum levels of combination between labour and equipment operations.

Availability of good quality tools and proper handling, storage and maintenance encourages good organisation of work. Skilful and harder working labourers can be discouraged by tools of poor quality. At the same time, any implement of road
works by LBT needs to have access to basic intermediate equipment as a prerequisite to achievement of meaningful quality work.

Equipment can be made available through hiring or ownership and the implementers require a proper management set up to control selection and utility. Otherwise they will end up paying directly or indirectly for equipment which was standing idle on the site.

3.3.2.1 Institutional and operational issues including training

Selection of tools and equipment is governed by issues grouped into: institutional issues; operational issues and training.

Institutional issues are those that can be influenced by policy and decision makers. They could be said to be the foundation of all progress but are outside the control of field practitioners. They include, local manufacturers’ capacity and development, quality assurance control, finance availability, procurement procedures and policy. These could also be termed as external managerial factors.

Operational issues are those covering operations and they represent those aspects of the project in full control of field practitioners, such as engineers, project coordinators and supervisors who influence practical aspects such as designs, specifications, procurement, performance data, costing, appropriate mix of equipment and maintenance of equipment.

Training issues are those covering works executor’s performance. Equipment operators and maintenance crew, workshops managers, users of equipment and works supervisors should be trained to understand the influence of availability and utilisation.

In order to establish proper and effective deployment of equipment in LBT, the stated issues should be addressed accordingly and in timely fashion. Failure to address any of them could lead to establishing non sustainable technology.

3.3.2.2 Tools

In LBT, tools operated by labour are meant to produce more or less the same results (for roads where it is applicable) as bulldozers and graders do in equipment based technology (EBT). For sure their selection should be in line with anticipated productivity of labourers and specifications for tasks to be performed. Tools should be of acceptable shape, size, weight, balance, strength, sharpness and of good construction. They should be acceptable to the user and suitable for the environment.

In Tanzania, tools in use (on studied projects) were selected based on specifications stipulated in the standard guide by ILO. A technical manual for labour-based roadworks in Tanzania is to be produced by the Ministry of Works. However, appropriate quality standards together with specifications in respect of various conditions are lacking among the implementers. Locally manufactured of tools targeted the agricultural industry and are far too weak to withstand the tough conditions of a road site. There are strong national and regional preferences for particular types of tools, shapes of heads and handles depending on environmental
conditions, culture and availability. The selected tools are governed by works
category and type; soils or material type, environmental conditions and availability.

The applicability of tools is governed by certain factors, such as, type of
work/activity, type of soil or material (including texture) and working condition
(such as weather). Therefore, it is impractical to try and have a universally
applicable list of tools for certain purposes in Tanzania as the country has a wide
range of conditions which affect the choice/selection of the appropriate tools.

3.3.2.3 Equipment

Equipment deployed in LBT roadworks are an intermediate between those used
for heavy construction and standard agricultural implements and so far there are
few standard designs. The type of equipment employed varies from project to
project even similar projects but located in different environment may employ
different equipment. The question of choosing equipment to be used goes together
with the mix of equipment operations with labour operations.

Equipment required for LBT should be able to withstand the adverse conditions
likely to be encountered, that is, it should perform effectively over an acceptable
working life. Also, it should be easily maintained and managed with locally
available skills.

Simple or intermediate equipment covers a very wide range of items that can
perform similar work although with a difference. Due to geographical and
economic conditions, which vary from country to country, it is not easy to
categorise and specify that one piece or design of equipment that works well in
one area will be successful in another, this applies also for a very large country
like Tanzania. For the selection of equipment key factors include availability,
organisational set up, work and working conditions, reliability and utilisation.

In the studied projects, equipment was deployed for haulage of material for
distances more than 300 m, and for watering and compaction. For rocky and dry
gravel excavation, deployment of labour was not practical, hence equipment was
deployed. Table 5.5 shows equipment and related activities in practice.
Table 5.5: Summary of deployed equipment

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Activity</th>
<th>Condition</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor/trailer Combination</td>
<td>Haulage of gravel and</td>
<td>0.3&lt;d*&lt;8</td>
<td>3 trailers for d*&lt;3 and 2 trailers for d*&gt;3, Output fixed at 6 to 8 trips per 8hrs day</td>
</tr>
<tr>
<td></td>
<td>fill material</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tipper trucks (7 tonnes)</td>
<td>Haulage of gravel</td>
<td>2&lt;d*&lt;15</td>
<td>Output fixed at 8 to 12 trips per 8hrs day</td>
</tr>
<tr>
<td>Tractor towed bowser</td>
<td>Watering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rollers</td>
<td>Compaction</td>
<td></td>
<td>Size varying according to availability and product quality</td>
</tr>
<tr>
<td>Tractor towed grader</td>
<td>Light grading</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(d^*\) denotes distance in km

3.3.3 Costing of Tools and Equipment

For all road projects, the target of the client (the owner), the implementing agency (the contractor), and the user (the public), is to have a product that fulfils the intended purpose at the minimum possible construction and maintenance unit costs. Deployed tools and equipment should be costed and charged accordingly in the project, particularly when establishing cost estimates. The importance of this aspect has to do with issues of replacement, sustainability and continuity of projects. Once pieces of equipment cannot be replaced (at the end of their economic life) from the internal resources of the project, it implies that there exists a subsidy from other programmes.

Budgeting and cost forecasting are often most conveniently carried out by means of unit costs and unit rates. The unit rate for a task is the cost of performing the task per unit of output, the unit cost for a resource is the cost of the resource per unit of time, the cost of the resource per unit of the resource.

For LBT, proper and reliable consideration in the determination of requirements affects the entire project cost. Planners should have as one of their basic planning tools, sound knowledge of technology implementation methods including tools and equipment to be deployed.

Budgeting covers one of the key project management aspects. Usually the project budget is divided into many items, major ones being:
• Labour
• Equipment
• Tools
• Materials
• Supervision
• Overheads and profit

Influence of tools, equipment and labour on costs is substantial. Proper management of the same deserves emphasis, the implementer needs to have a check list of tactics that may be used to reduce costs.

A conceptual sequence for LBT works planning to attain costing inputs was developed by authors and compared with practical experience. The costing procedure is usually performed at the budgeting level, close to the end of the entire planning process.

Figure 1: Flow chart for LBT work planning (conceptual only)

#### 3.3.3.1 Costing of tools

Costing of tools relies on procurement set up, productivity outputs, sources, and estimation abilities.
General experience indicated that the cost of tools was small compared to that of labour in roadworks that employed LBT. When the works were carried out by force account approach, labour was directly employed by the project executing agency, that is, government administrations, who unfortunately overlooked the importance of tools due to the assumed low costs involved. This tendency was attributed to lack of incentives to examine entire project costs and keep them low; together with ignorance of the impact of tools of poor quality on productivity. Private contractors worked on normal business principles, that is, project costs conscious issues take the lead.

General practice in costing use of tools includes:

- initial cost (market price);
- replacement rate in respect of activities involved (i.e. life span); and
- maintenance costs (where applicable).

Conceptual procedure for costing of tools to be deployed in the project as developed by the authors basing on practical experience is as outlined here below:-

- Determine the number of person days (pd) required per activity that should deploy tools (irrespective of tool type)

  \[ pd_i = \frac{b}{a} \]

  \( a \) is the standardised or from general experience task rate (units per person day)

  \( b \) is number of total units of work to be performed on activity (i).

- Determine the total number of person days (f), for all (s) activities that should deploy tools (irrespective of tool type)

  \[ f = \sum pd_i \quad \text{where, } i = 1,2,3,...,s \text{ (activities)} \]

- Determine the cost of all tools to be deployed. Can be done as described in step 6 of Figure 1. The obtained amount is (e).

- Determine the cost of tool person day (CTpd) assuming activity person days is equal to tool person days.

  \[ CT_{pd} = \frac{e}{f} \]

- Determine the cost of tools for each activity (CTi)

  \[ CT_i = CT_{pd} \times b \]

Factors to be observed in application of this procedure include:

- Number of tools, which should accommodate possible losses, damages and salvage;
- The assumption that types of tools need not be regarded separately for simplicity;
- Cost should include all related logistics.
3.3.3.2 Costing of equipment

Although LBT emphasises an extensive use of labour rather than equipment, a significant part of the costs and attention of project implementers is devoted to the use of appropriate equipment. Use of equipment on site is the most costly operation during the whole roadworks execution period. Therefore it is of vital importance to spend time planning equipment use carefully so as to know the costs and ascertain all management aspects irrespective of the size or type or mode of acquisition of the equipment.

No matter the technology, the key problem where equipment is involved is effective and efficient management, availability and utilisation.

Whatever the approach, hiring or owning the equipment, the practitioner should have access to the equipment at a reasonable price which is determined or governed by sufficient supply.

In roadworks, rates to be charged against activities executed using any piece of equipment in the project, should clearly reflect all operating, investment and depreciation costs. This shall ensure replacement from internal resources allowing the project to be sustainable.

In LBT for roadworks, the costing of equipment doesn't differ from the practice adopted when deploying EBT. The issue remains vital as it contributes to effectiveness, efficiency and competitive implementation of the technology.

Based on experience from investigated projects, costing of equipment requires establishment of:

- quantities of work to be performed;
- standardised (in local environment) output rate;
- cost of that equipment per unit time; and
- duration the equipment shall spend on site for the project.

Simplified conceptual steps and relations that may be followed in costing equipment have been developed considering the above key inputs. Major assumptions made include: operations do not require deployment of different types of equipment with varying hire rates and output rates implying different utilisation. The following steps are proposed:

- Determine activities (s) that shall deploy the same type of equipment including quantities of work for each activity (q_i) and duration (d_i) basing on local conditions output rates (r_i).
  \[ d_i = \frac{q_i}{r_i} \text{ where } i = 1, 2, 3, ..., s \]

- Determine cost of having the equipment per unit of time (n), usually take prevailing market hire rates.

- Determine the cost of using the equipment on each activity (h_i)
  \[ h_i = d_i \times n = \frac{q_i}{r_i} \times n \]

- Determine total cost of the equipment while in use on site (m_i)
  \[ m = \sum h_i + k \]
where \( k \) are other related costs such as mobilisation, demobilisation contingencies and idle time.

- Determine the actual equipment cost per unit of time of effective utilisation \((w)\) and use it for costing and budgeting.

\[
w = \frac{m}{d_i}
\]

### 3.3.4 Management of tools and equipment

Management is a process whereby managers create, direct, operate and control complex organisation using human effort to achieve the intended objectives. The project management may be defined as the overall control of the process to optimise the major attributes of the process, that is, quality, schedule and cost. The project implementation starts with the planning phase where major decisions are made concerning factors such as, project size and complexity, location, time constraints, desired level of quality and resources inputs. Proper management of the planning and decision process is therefore extremely important, as it determines proper implementation of the construction phase.

Due to the investment involved in road networks, it is important and appropriate to consider managing it in a businesslike manner. That would allow roads construction and maintenance management issues to be termed as getting the right materials, equipment and people to the right place to carry out the right work at the right time and cost.

For general practice, practitioners need to be conversant with:

- handling and management of labour, equipment and other factors that affect productivity;
- general construction outputs and environmental factors that dictate deploying particular types of tools and equipment prior to project take off; and
- reliable and proper co-ordination with manufacturers of tools and equipment. Their experiences of technical problems encountered should be provided as feedback so that manufacturers can be exposed to actual needs in prevailing conditions for development and testing.

#### 3.3.4.1 Management of tools

Management of tools requires acceptable organisational set up co-ordinating all key stakeholders. LBT practitioners should keep large stock of tools, and think carefully about tools they intend to procure. Based on practical experience, it should always be possible to estimate actual requirements, possible losses, and the quality of tools which would be durable according to environmental conditions. This might be expensive but will be worth it in terms of long term benefits. In order to keep track of tools, it is essential to set up simple tools planning and reporting systems. The information from records should be used to monitor and analyse costs, durability and condition of different batches of tools for purposes of improvement and setting a sustainable trend for future purchases and utilisation. Unfortunately, from studied projects, this does not seem to be the case in practice.

Broken, damaged and worn out items should be replaced or sharpened (where applicable) in the course of work execution. For the purpose of ensuring longer
life, control of misuse or theft of tools, proper handling, storage and maintenance deserve emphasis.

For the tools to be deployed, the implementers:
- should be conversant with specific tools requirement in respect of different activities including designs, specifications and criteria of selection;
- should know the source of tools (suppliers and, or manufacturers) within the project locality;
- should know and adopt proper procurement procedures and set up of main and site stores; and
- should observe effects of different types of tools on labourers’ productivity

Observed practice on tools management aspects revealed:
- During procurement, specification and design of tools are not observed to suit roadwork conditions. The procurement system of buying from cheapest quoted price contributes to poor quality tools, although this is not quantified. Also, it has been observed that some procurement officials cannot appreciate practical differences between some tools, they are committed to prices only. For example, the difference between mattocks and pickaxes was not clear to some purchasers. The purchaser assumed the two tools are for the same work.
- Verification of quality of tools is not done due to lack of testing facilities.
- Local manufacturers are not encouraged to produce tools specifically for roadworks. Requirements at regional, zonal or national level are not co-ordinated to give an indication of the demand potential.

Management of equipment
For equipment deployed: effective, efficient and reliable implementation can be achieved if key stakeholders are conversant with the following issues:
- different types of equipment required and available for the project and criteria to be used for selection;
- productivity and output rate of available equipment (rated and actual as per the existing conditions);
- modes of acquisition available and associated responsibilities in risk sharing;
- operator knowledge and training required; and
- proper scheduling of activities and monitoring utilisation to avoid paying for pieces which are idling unnecessarily on the sites.

Observed practice indicated the existence of a low level of availability and utilisation of equipment. This was attributed to lack of spare parts, poor maintenance, insufficient planning and co-ordination plus misuse of the programme equipment.

3.3.5 Mixing of Labour and Equipment Operations
In LBT there exists an issue of optimum combination of equipment and labour operations for required project delivery timing and quality achievement.

The mixing of labour and equipment operations depends on the activity sequence, construction output and labour and equipment input levels. General practise of LBT indicates that many activities are executed exclusively by labour using non
mechanical tools such as hoes, spades, shovel and wheelbarrows while for activities which cannot be performed efficiently and effectively by labour such as haulage and placing of materials, equipment is deployed.

The concept of mixing is twofold: labour to work with the equipment on the same category of work or labour working on activities preceding or following those performed by deploying equipment.

The question of mixing operations done under LBT in roadworks, is dependent on the sequence of work activities and technological input. Approaching optimum mixes of operations that require labour input exclusively and those that deploy equipment solely, could be a complicated aspect. However, key issues to observe are labour outputs, equipment outputs and construction output. Gang size and co-ordination between performers of different activities, contributes to decisions of optimum level to be achieved, apart from type of equipment and tools deployed.

General observations shows that it would require about 25 labourers to support a 5 five tonne flat truck, hauling about 29 m³ of firm soil per eight hours day over an average condition haul distance of 1.5 km, for excavating, loading, unloading and spreading [Gichaga and Parker, 1988, pp 133]. This concept can be the basis for management decisions, for instance to hire on the basis of the critical labour and equipment input to ensure effective output, seeking always to approximate the maximum achievable output or optimum.

Observed practice in Tanzania is that normally a combination of tipper trucks (seven tonne) and tractor trailers is used for haulage of gravel whereas excavation, loading and spreading is done by labour. However, sufficient quantification of practical data is missing, weakening the argument for advocating adoption of similar practices in other places. The method appears to be efficient but it should be supported by field data and analysis stating surrounding limitations.

3.3.6 Discussion of Observations

- Non observance of quality of tools during procurement and weak emphasis on testing the same on delivery could be attributed to ignorance of practitioners about the impact of good tools on labourers output. Also, lack of encouragement of local manufacturers does not give room to practitioners to specify sources of tools and thereby monitor performance and participate in development, improvements and testing. Continuance of such practice could lead to problems such as, discouraging labourers, increasing costs due to increment in work days required and making the technology unsustainable.

- Procurement procedures which allow purchasers who are not conversant with site working conditions also contribute to non compliance with actual requirements. Losses incurred in this fashion could be significant if the technology were to be adopted nation-wide.

- Co-ordination among manufacturers and supervisors, together with training of users, would allow development and simplification of the technology.

- The logical approach on costing of tools and equipment for each activity is vital to establish a basis for budgeting, monitoring and evaluation of the implementation;

- Shortcomings exist in the practical implementation of deploying tools and equipment on costing and management. Also, awareness is lacking about impacts that can be realised with a proper mix labour and equipment operations in practice.
3.3.7 Recommendations

1. Labour-based technology for road construction, rehabilitation and maintenance in developing countries such as Tanzania is appropriate. Scientific interventions should target deployment of quality tools with emphasis on local manufacturing, towards application of the technology nation-wide. Potential needs at regional, zonal and national levels should be co-ordinated. Local manufacturers should be approached and encouraged to improve product quality with the target of satisfying roadworks site conditions without abandoning normal customers. Promotion of the technology at macro level should involve making it sustainable. Based on field studies it was found necessary to:
   - standardise at zonal level, local environmental conditions affecting selection of tools and equipment, together with practical output rates;
   - prepare guidelines on logical approaches to selection criteria and costing of tools and equipment; and
   - document and publish the established and acceptable approaches and standards as a handbook for practitioners.

2. Deployment of tipper trucks (seven tonnes) for haulage of material has shown acceptable performance making the equipment acceptable for LBT. However, performance data such as output rates, costing approach and management should be quantified for development and sustainability. Practitioners such as contractors, require advice and guidelines on appropriate approaches to be adopted during implementation especially on choosing between available haulage alternatives.

3. A data collection and banking system should be established. Emphasis should be given to output rates, cost of inputs as monitored during implementation, tools and equipment losses and damages.

4. Awareness seminars should also include:
   - importance of tool quality, selection criteria and costing. With elaboration on the effects of selection and quality on productivity hence person days required, implying costing.
   - emphasis on procurement procedures which observe good quality together with cost constraints.

   involvement of local tools manufacturers to enlighten them on labour-based technology in roadworks site conditions.

References


3.4 EQUIPPING TRAINED LABOUR-BASED CONTRACTORS — THE GHANAIAN EXPERIENCE

E. N. K. Ashong (BSC, MSC, MGhIE), National Co-ordinator, Department of Feeder Roads, Accra, Ghana

3.4.1 Introduction

The issue of whether or not to equip trained labour-based contractors looks to have been put to rest with the acceptance of the fact that trained labour-based contractors need some basic equipment. The source of this equipment is the subject of argument.

The consensus which looks to be that of the majority now is that trained contractors should be equipped but "appropriately." What is considered "appropriate" can vary from country to country and even from region to region within the same country. Certain key points need to be considered in determining the degree of "appropriateness" of equipment packages. Apart from physical/terrain considerations, issues such as the performance of the existing construction industry and the equipment back-up services need to be given serious consideration. The matrix will be incomplete without a serious look at the payback period vis-à-vis the need for continuous "flow" of work for the contractor and the application of "fair" schedule of rates.

Based on the experience gained in Ghana since 1986 with a starting number of seven equipped contractors, this paper intends to look at the managerial aspect of the problem with a view to making salient recommendations that will go a long way to avoid and alleviate the problems encountered.

3.4.2 The Argument

There are two schools of thought on the issue of equipment supply to labour-based contractors. The first group's argument can be summarised thus:

"Trained labour-based contractors should be 'thrown' straight into the competitive environment, like all other contractors to fend for themselves. The success in such an environment is a real measure of success."

The other group's argument can also be summarised thus:

"The development of a successful and sustainable labour-based programme should be systematic and every new step must be totally evaluated to optimise the chances of success. Being a new technology, there is a need to guide and guard the contractors in the early formative years in terms of capacity building, and technical/managerial competence."

Ghana belongs to the second group. The Ghana labour-based programme started in 1986. Up to date 93 contractors have been trained out of which 56 have been equipped.
3.4.3 The Status of the Ghana Programme

The Ghana programme started in 1986 with technical support of the ILO. Initially seven contractors were trained in the technology and supplied with the following pieces of equipment at a total cost of US$150,000 on loan, recoverable in four years with interest. This interest is applied to the original loan at the prevailing banking rules and regulations.

a) 3 tractors
b) 6 trailers
c) 1 tipper truck\(^*\)
d) 1 towed water bowser
e) 1 pedestrian roller
f) 1 chain-saw
g) A set of hand tools

The subsequent equipment packages included a pick-up and a tipper truck which were released to each contractor from the onset.

**Table 1: Regional distribution of labour-based contractors**

<table>
<thead>
<tr>
<th>SN</th>
<th>Region</th>
<th>Total trained</th>
<th>Total equipped</th>
<th>Total non-equipped</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Greater Accra</td>
<td>4</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Eastern</td>
<td>15</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Volta</td>
<td>8</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Central</td>
<td>9</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Western</td>
<td>10</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Ashanti</td>
<td>10</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Brong-Ahafo</td>
<td>11</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Northern</td>
<td>10</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>Upper-East</td>
<td>8</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>Upper-West</td>
<td>8</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>93</td>
<td>56</td>
<td>37</td>
</tr>
</tbody>
</table>

One trained contractor has been expelled for non-performance. The programme, which started on a pilot basis in the Western Region and on a demonstration basis in Ashanti and Brong-Ahafo Regions, is now nation-wide.

**Table 2: Rate of equipment supply**

<table>
<thead>
<tr>
<th>Year</th>
<th>No of Cumulative no</th>
<th>No of Cumulative</th>
<th>Cumulative</th>
<th>Cumulative no</th>
</tr>
</thead>
</table>

\(^*\) Hired by the contractor from a pool and released eventually to the contractor after the completion of the Trial Contract and during the execution of the first Standard Contract.
contractors trained  |  of contractors trained  |  contractors equipped  |  no. of contractors equipped  |  of non-equipped contractors
--- | --- | --- | --- | ---
1987  |  6  |  6  |  3  |  3  |  3
1988  |  7  |  13  |  4  |  7  |  6
1989  |  16  |  29  |  12  |  19  |  10
1990  |  6  |  35  |  2  |  21  |  14
1991  |  6  |  41  |  5  |  26  |  15
1992  |  14  |  55  |  -  |  26  |  29
1993  |  16  |  71  |  -  |  26  |  45
1994  |  10  |  81  |  28  |  54  |  26
1995  |  12  |  93  |  -  |  54  |  38
1996  |  -  |  93  |  2  |  56  |  36
1997  |  -  |  93  |  -  |  56  |  36

Table 3: Support for equipment

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of sets</th>
<th>Donors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987/1989</td>
<td>21</td>
<td>World Bank</td>
</tr>
<tr>
<td>1991</td>
<td>5</td>
<td>Ghana Government</td>
</tr>
<tr>
<td>1994</td>
<td>16</td>
<td>DANIDA</td>
</tr>
<tr>
<td>1994</td>
<td>12</td>
<td>USAID</td>
</tr>
<tr>
<td>1996</td>
<td>2</td>
<td>IFAD</td>
</tr>
</tbody>
</table>

Table 2 shows how the Ghana programme has been ‘prodding’ on with equipment supply to trained contractors and the arrears required.

Table 3 indicates that only 8.9% of the equipment supply so far is from Ghana Government source. This shows a high degree of donor-driven equipment supply.

### 3.4.4 Factors Affecting the Contractors' Equipment Loan Recovery

Each equipped labour-based contractor is supposed to re-pay the equipment loan with interest in four years. The assumption is that the contractor will be guaranteed continuous work within this loan recovery period. Due to budgetary constraints in a developing economy like Ghana, this condition has been very difficult to fulfil. The contractors’ performance in terms of the servicing of equipment loan is affected by the actions of a tripartite group made up of the contractor himself, the client and the loan management bank. The roles played by this group towards the speedy recovery of the equipment loan are summarised in Figure 1. Some few explanations may throw more light on some of the issues summarised in figure 1.
3.4.4.1 Only time tested equipment should be procured

Competitive tendering has led to the procurement of 'unknown' pieces of equipment which have led to very low outputs. In every country there are some familiar and tested brands for every type of equipment. Selective tendering should be used as much as possible in order to take advantage of such experience.

3.4.4.2 Equipment adequacy

The tipper truck contributes about 32% of the equipment loan but does not contribute significantly towards physical output since it is basically used for the long distance haulage of basic inputs like cement, fuel and iron roads. The tipper should either be replaced by a less expensive low-bed truck or the contractors should be assisted to procure the tipper truck after a period of two years within which the contractors’ loan servicing performance would have been determined and the size of the original loan would have been reduced drastically.

3.4.4.3 Maintenance of proper construction management practices

The actions of the contractor should always be geared towards optimum productivity and hence speedy servicing of the equipment loan. The following are samples of bad construction management practices:

- use of worn-out tools
- long delay in servicing of equipment
- diversion of money meant for salaries and wages
Figure 1: Contributory factors for speedy equipment loan recovery

<table>
<thead>
<tr>
<th>The Client</th>
<th>The Contractor</th>
<th>Loan Management Bank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selection and training of contractors</td>
<td>Continuous production of at least 1.5km of gravel road per month</td>
<td>Assessment of financial capability of contractors</td>
</tr>
<tr>
<td>Procurement of equipment</td>
<td>Maintenance of proper construction management practices</td>
<td>Interest rates fixed at acceptable level</td>
</tr>
<tr>
<td>Equipment adequacy</td>
<td>Maintenance of equipment</td>
<td>Supply of adequate information on loan recovery to the client and contractor</td>
</tr>
<tr>
<td>Prompt payment</td>
<td>Establishment of private credit facilities</td>
<td>Monitoring of equipment management and maintenance</td>
</tr>
<tr>
<td>Ensuring continuous work for the contractor</td>
<td>Need for a strong association for interest protection and addressing common problems</td>
<td>Favourable conditions for collateral and guarantees</td>
</tr>
</tbody>
</table>
Years of experience have shown that the following can further enhance speedy loan recovery:

- Denomination of the loan in the currency of the beneficiary country instead of that of the donor;
- Procurement of only time tested equipment; and
- Quarterly interest application instead of monthly.

To date, 26 contractors should have finished paying for their equipment loans. Despite the numerous initial problems created by the above itemised factors, about 70% of this number have finished paying back the loan with the first completing in a record time of three years. The outstanding 30% have small balances to clear.

### 3.4.5 The Way Forward

There are currently 36 contractors yet to be equipped. There are 110 political districts in Ghana. Decentralisation of governance to the local/district level is being pursued vigorously in Ghana. The Department of Feeder Roads (DFR) is one of the targeted agencies to be decentralised. The vision of DFR is to evolve a district-based sustainable maintenance strategy with equipped labour-based contractors as the executors. There are 102 rural and 8 Urban/Metropolitan political districts in Ghana. It is envisaged that DFR will have on the average one labour-based contractor per district to be in charge of routine/recurrent maintenance works. Thus eventually 110 contractors, will be trained in the technology. The following are the emerging problems:

- Moving the number of trained contractors from 93 to 110, that is training 17 more contractors
- Equipping the current outstanding 36 contractors and the additional 17 DFR does not intend to train more new contractors until the problems with the equipping the outstanding 36 contractors appropriately have been solved. The current capacity is adequate for the maintenance works since the contractors who have finished paying for the equipment can be engaged to work in more than one district. The training will now concentrate on maintenance and management.

The outstanding 36 contractors need to be equipped appropriately to execute routine/recurrent maintenance. The Ghanaian labour-based contractors are going to be classified into three groups based on equipment holding and the type of work to be executed. The recommended equipment packages listed below were arrived at taking cognisance of the fact that DFR's main thrust for the immediate future is maintenance. The classification will ensure:

a) healthy competition in both quality and performance
b) early loan repayment
c) maximum utilisation of limited funds
d) larger coverage of contractors implying more coverage of the road network to be maintained.

The level of equipment supply should depend on the network condition mix of the country and the thrust of the road authority's operations. Ghana started from level
one because at the inception of the programme, the condition of the network required massive rehabilitation works. The rehabilitation backlog has been cleared appreciably and the thrust of DFR's operation now is maintenance and the stabilisation of the existing network hence we can now afford to equip from level three. The recommendation therefore will be to look at your problem and equip contractors accordingly.

An incentive element is built into this approach because contractors at the lower level can either be assisted with further equipment to move up to the next level or they can privately augment their equipment holding to move up. On the other hand, due to non-performance and equipment loss, contractors can be demoted.

The "appropriate" equipment for each class is as follows:

**Level one:**
This level of contractors can handle any type of rehabilitation and maintenance contracts.

Current package for equipped contractors so far:

a) 3 tractors  
b) 6 trailers  
c) 2 pedestrian rollers  
d) 1 water bowser  
e) 1 tipper truck  
f) 1 pick-up  
g) towed grader**  

Minimum number of trained supervisors: 3  
The cost of this package is about US$150,000.

**Level two:**
This level of contractors will handle routine/recurrent and periodic maintenance contracts. The recommended equipment holding is as follows:

a) 2 tractors  
b) 2 trailers  
c) 1 bowser  
d) 1 pick-up  
e) 1 towed grader  
f) 1 pedestrian roller  

The cost of the package is about US$70,000.00

** To be procured later by contractors.
Minimum number of trained supervisors: 2

**Level three:**

This level of contractors will handle only routine/recurrent maintenance contracts. The recommended equipment holding is as follows:

a) 1 tractor
b) 1 trailer
c) 1 pedestrian roller
d) 1 motorbike

The cost of the package is about US$30,000.

Most countries do not have local contractors and works are executed mainly by foreign contractors. Ghana at the inception of the programme had a vibrant construction industry dominated by local contractors and therefore taking the bold decision to involve the private sector in the programme instead of using direct labour was considered not too risky. Most countries are still using direct labour for labour-based works despite the clearly identified attendant problems. The creation of a vibrant core of local contractors can be started cautiously using small scale labour-based contractors.

### 3.4.6 Setting Up of Plant Pools

Ghana has enormous experience in the performance and contribution of plant hiring companies although this experience is largely limited to capital-intensive contractors. All the large government owned and privately established plant hiring companies have folded up and some are now using the remnants of their equipment stock to execute contracts directly. The reasons for the failure of these companies are numerous, the principal among them being:

- non-payment by contractors;
- large overheads
- acquisition of equipment by contractors due to high hire charges by hiring companies;
- a temptation on the part of the hiring companies to enter the construction industry; and
- high cost of haulage of equipment over long distances.

DFR has indirectly established a protected plant pool for the non-equipped contractors. This category of contractors are the only ones allowed to hire DFR equipment. The hiring cost of the equipment is deducted at source from payments for work done. This system has worked well till now because the non-equipped contractors are awarded contracts for the installation of culverts and the approach fillings. The scramble for equipment even in this system can be intensive.

Experience from other countries, like Tanzania shows that plant pools have not helped in the establishment of labour-based programmes because other stakeholders like capital-based contractors and farmers have increased the scramble for equipment to the disadvantage of the small-scale labour-based
contractors. The situation becomes aggravated by the fact that the labour-based contractors need to ensure continuous work to keep up the morale of the workers, especially the casuals. Where resources are available, consideration should be given to the setting up of a protected plant pool as a supplementary equipment source to the current situation of a direct supply of equipment loans to trained labour-based contractors. The advantage is that the cost of hiring of any piece of equipment can be deducted at source by the client.

3.4.7 Conclusion

Trained labour-based contractors need equipment. The source of equipment can be: the client through equipment loans, outright ownership by the contractor or through protected plant pools. The equipment package should be "appropriate" for the work available in order not to overburden small-scale contractors with limitless loans. Labour-based programmes should be designed in such a way as to ensure an optimum mixture of equipment package instead of over-equipping contractors making them to feel that the programme is just a "safe haven" for the acquisition of equipment for other works.
3.5 LABOUR-BASED PROGRAMME: UGANDA COUNTRY PAPER

Eng. W. E. Musumba, Principal Executive Engineer, Road Maintenance Contracts, Ministry of Works, Transport and Communications, P O Box 10, Entebbe, Uganda

3.5.1 Background

The Government of Uganda has since 1986 reconstructed/rehabilitated a sizeable portion of its entire road network which necessitated the putting in place of an effective road maintenance system to protect the investment. The government has as one of its highway network policies "the development of the local construction industry as a measure of ensuring a sustainable road network". The government has endorsed the labour based contracting option as one of its appropriate technologies.

The paper discusses some of the labour-based projects that are currently being or have been recently undertaken by government. The paper looks at the enabling environment provided by the government and how the implementers have been equipped in undertaking the different labour based projects/programmes.

A number of projects deploying labour-based technology are discussed. The use of this technology now has a firm foothold in Uganda as is evidenced by a number of such projects currently under design implementation or design.

3.5.2 Introduction

Since 1986 the Government of Uganda has reconstructed/rehabilitated 60% of the main roads and 20% of the feeder roads at a total cost of over US$300 million. There was therefore mounting pressure to have this enormous investment protected. In 1992, under the auspices of the Road Maintenance Initiative, an in-depth analysis of problems related to road maintenance was undertaken. This led to the formulation of revised policies and strategies which now form the basis on which the contracting option was adopted for roadworks. The government's medium-term highway network policy is the following:-

i. The provision of an efficient, safe and sustainable main roads network as a support for accelerated integrated development and consolidation of peace and national unity.

ii. The development of the local construction industry as a measure of ensuring a sustainable road network.

iii. To undertake alleviation programmes.

The government has adopted a deliberate policy of increased use of the contracting option with the target of contracting 80% of all roadworks by the year 2000. It was however noted that the local contracting industry was ill-equipped and could only develop gradually through affirmative action by government. Further experience had shown that potential small scale contractors lacked
experience in quoting and tendering generally and hence it became extremely
difficult from them to break into the market. The adoption of Fixed Unit Rates
(FUR) was therefore found to be a most feasible approach.

The objective of the contracting initiatives is to develop in the local contracting
industry a sustainable capacity for roadworks using small scale contractors. Both
the Ministry of Works, Transport and Communications, and the Ministry of Local
Government have embraced the policy of use of contractors as the most cost
effective means of handling roadworks.

The Ministry of Planning and Economic Development has also co-ordinated
various pilot projects with the aim of creating employment and alleviating poverty.
A number of such projects are discussed.

3.5.3 The Labour-based Contracting Programme
(LBCP)

3.5.3.1 Basis
The policy of the Ministry of Works, Transport and Communications (MOWTC)
is to increasingly use private contractors for cost effective and efficient
operations. The old policy, which was highly dependent on force account
operations, had several constraints which the increased use of contractors aims at
minimising.

3.5.3.2 Project data
The Labour-based Contracting Programme (LBCP) is financed by the
Government of Uganda. Over US$3.0 million is annually budgeted for the
programme. The annual turnover for a typical lengthman contractor (maintenance
of 2km) currently stands at US$360.

The LBCP which started in January 1993, is an ongoing routine activity budgeted
for annually under the road maintenance recurrent budget.

3.5.3.3 Project activities
The programme targets all the manual routine maintenance activities that are
normally carried out on both paved and unpaved (gravel) roads. The list of
activities includes the removal of obstructions, drainage repairs, filling of potholes
and grubbing (for unpaved roads only), vegetation control and tree planting.

3.5.3.4 Equipping of contractors
Initially, tools were provided to the contractors. With the liberalisation of our
economy, the contractors are responsible for provision of their own tools, which
are readily available. The Ministry, however, still provides expensive tools like
wheelbarrows to interested contractors.

The contractors are encouraged to have the following handtools:-

i. Wheelbarrow

ii. Hoes
iii. Shovels/spades  
iv. Rakes  
v. Slashers

### 3.5.4 Fixed Unit Rate Mechanised Contracting Programme

#### 3.5.4.1 Basis

According to the new maintenance strategies, all routine mechanised maintenance will ultimately (by the year 2000) be carried out by contract. Another strategy is that aimed at capacity building of local contractors. This programme was started to answer to the two above strategies.

#### 3.5.4.2 Project data

This is an annual programme whereby the government of Uganda allows a percentage of the budget equivalent to at least US$3 million. This programme is intended to be a short term stop gap, which will eventually give way to local competitive bidding.

#### 3.5.4.3 Programme activities

This programme is targeted at developing contractors to carry out routine mechanised maintenance. Activities include the following; grading, drainage repairs, spot regravelling of unpaved roads, pothole patching and shoulder repairs for paved roads.

#### 3.5.4.4 Equipping of contractors

In an effort to offer affirmative support to the emerging contractors, MOWTC adopted a policy whereby contractors can now hire idle equipment to the contractors. Those in a position to repair broken down equipment can repair and hire the same and utilise the equipment for a given period to offset the costs. Contractors are at the same time encouraged to acquire their own equipment.

### 3.5.5 The Uganda Transport Rehabilitation Project

#### 3.5.5.1 Basis

The policy direction for the Ministry of Local Government (MOLG) is more less the same as that of Ministry of Works, Transport and Communications (MOWTC), with different targets for attaining local contracting capacity. The Ministry has among its objectives to introduce labour-based methods of road maintenance and feeder roads rehabilitation wherever cost-effective.

#### 3.5.5.2 Project data

This is a component of the Feeder Roads Component of the Transport Rehabilitation Project. It is financed by the International Development Association (IDA), Nordic Development Fund (NDF), and Government of Uganda (GOU). The value of the works is US$8.7 million over a four year period starting in 1995.
The annual turnover for a typical contractor is in the range of US$240,000 for rehabilitation works of about 20 - 25 km.

### 3.5.5.3 Project activities

The relevant project activities include rehabilitation of 680km and maintenance of 880km of feeder roads in four districts of Mbale, Kapchorwa, Tororo and Pallisa of Eastern Uganda. The project proposes to use labour-based methods in combination with light equipment like farm tractors, trailers, pickups, motorcycles, pedestrian rollers etc.

Technical assistance (TA) has been provided to steer the programme. Notable in the TA team are local expert staff and this provides another area of local capacity building.

### 3.5.5.4 Equipping

This project attempts to address the main constraint facing contractors, lack of equipment. The project has procured the necessary equipment and tools. A financing/leasing company has been formed and will be responsible for the leasing of the equipment. The leasing company will also be linked to the banking system, which will handle payments and provide working capital to contractors. This leasing arrangement has been a highly motivating factor for the aspiring contractors. Each contractor has been equipped with the following:

- 1 pick-up
- 1 tractor with trailer
- 1 tipper
- 1 set of culvert mould
- 2 double drum rollers

### 3.5.6 The African Development Bank (ADB) Rural Feeder Road Rehabilitation and Maintenance Project.

#### 3.5.6.1 Basis

Basically all feeder roads projects are required to apply effective routine maintenance on the rehabilitated roads.

#### 3.5.6.2 Project data

The Project is financed by African Development Bank (ADB) (US$24.0 million) and Government of Uganda (GOU) (US$16.0 million). About 20% of the above funds is meant for manual routine maintenance.

#### 3.5.6.3 Project activities

Labour-based routine maintenance of 2400km of rehabilitated roads. Activities include removal of obstruction, drainage maintenance, pothole filling, grubbing and vegetation control.
3.5.6.4 Equipping of contractor
The project provides the required tools, which include wheelbarrows, hoes, shovels, rakes, slashers, etc. Decentralised payments are made.

3.5.7 Re-Integration of Demobilised Soldiers Programme (RDSP)

3.5.7.1 Basis
The overriding aim of the project is to give demobilised soldiers a chance to be integrated in society through acquisition of skills and gainful employment.

3.5.7.2 Project data
The funding is through a grant of DM4.0 million from the Government of Germany.

3.5.7.3 Project activities
The demobilised soldiers were formed into labour units responsible for opening and rehabilitating of feeder roads in ten districts. Activities include reshaping, selective regravelling, provision of concrete culverts and follow up maintenance.

3.5.7.4 Equipping of hired labour
The labour units are equipped with the necessary tools. Individuals are given the necessary skills in road rehabilitation, maintenance and fabrication of culverts.

3.5.8 MPED/ILO Labour Intensive Projects

3.5.8.1 Background
In Uganda, the ILO has also been instrumental in promoting labour-based programmes. This was initiated in 1981 under the Ministry of Planning/ILO Labour-Intensive Special Public works Programme (LISPWP). The Labour Intensive Works Unit (LIWU) was established in the Ministry to pilot and promote the various LISPWP projects.

LIWU is currently led by the Under Secretary of MPED as its Chairperson and a National Co-ordinator for the day to day operation of the unit. Technical personnel from other government departments are co-opted into the unit according to the needs of each particular project.

Some of the projects implemented by LIWU are discussed below.

3.5.8.2 Multi-Sectoral Project in Karamoja
This employment creation and infrastructure building capacity was implemented between 1985 and 1995 with a breakdown during the 1986-87 war. The project involved the building of schools, markets, the construction of boreholes and afforestation works with funding from UNDP (for the technical assistance) and the Government of the Netherlands for the investments (about US$9 million). During the first phase, implementation started in the districts of Moroto and Kotido, later on all investments were concentrated in Kotido district. Local people
provided the local materials and served as unskilled labour on all the construction works. Some were trained on-the-job to do some skilled jobs like carpentry and masonry.

3.5.8.3 Rehabilitation Project in Luwero District

This was an emergency relief programme implemented in Semuto sub-country, one of the most war-affected areas in the Luwero Triangle. It was a quick intervention project designed to help people resettle in their homes. It involved construction of schools, co-operative stores and roads, protection of water points, and promotion of agroforestry funded by UNDP. One other important element promoted in this project was banking of mandays in exchange for building materials and opening up of agricultural fields.

3.5.8.4 Promoting Local Building Materials Project

This was a research programme funded by the Austrian Government to test the use of improved local building materials in a few selected villages both outside and within the above mentioned project areas. The research conducted involved development of stabilised soil sun-dried bricks and the use of papyrus for roofing.

3.5.8.5 Southwest Feeder Road Project (1986-94)

The UNCDF/UNDP funded project involved the rehabilitation of over 600km of feeder roads in six districts. The rehabilitation of the feeder roads was done mainly by equipment intensive methods. However, operations like culverting were done by small local contractors. Maintenance was also contracted out to small contractors.

3.5.8.6 Masulita Development Project

The integrated rural-development project was designed to reactivate the local economy of another war-ravaged area using the experiences of the Luwero project. The situation at the beginning of the project was that of an area with impassable, overgrown roads, poor hygiene standards with limited and seasonal sources of drinking water, a high number of uneducated teenagers and, a general lack of facilities to improve the agricultural production. Therefore, the project was designed to improve accessibility to and within the area, to boost the income of the population and to provide primary health-care. The project’s outputs include: feeder roads, protected water points, easier access to credit for the poor, and improved hygiene. The project used a community-based approach, and many of the community’s workers have acquired trade skills in carpentry, masonry, road reconstruction and maintenance works. These workers simultaneously boosted their income through the wages earned and can now access credit to improve their productive activities. A quantified analysis reveals that over 80,000 days of paid employment had been created by 31/07/97 and Ushs102,409,570 paid in wages to the local workers. In addition, Ug Shs 25 million was spent on buying local materials from the area. These included sand, hard core, timber and murrum.
3.5.9 Experiences and Recommendations

Experiences from the different projects indicates that prospects for the labour based technology are bright. However, it is apparent that the following need attention:

i. At the moment, the implementing agencies are apparently initiating projects on their own. There is need for co-ordination between the different implementing agencies, especially in areas of policy and training.

ii. Equipping of the implementers even with simple tools is still a major problem. Hardly any leasing/plant hire pool exists in this country. The impact equipping arrangement under the Uganda Transport Rehabilitation Project is yet to be assessed. Future projects should address this critical area.

iii. Related to the problem of equipping is the use of wrong tools, evident in most projects. For example, when should a shovel be used instead of a spade. Training components should be a must in all projects.

iv. Because of lack of co-ordination the documentation is basically agency specific. Standard labour based management guidelines should be developed.

v. There is limited continuity. Projects are initiated and implemented but there is hardly any follow-up thereafter. It is hoped that the new project, Support to Labour-Policy Promotion Initiative, will address most of the above issues. The project aims at achieving the following:-

1. Labour-based approaches are integrated into the national planning process and a policy adopted.

2. Technical and administrative capacity to implement labour-based works is created in the public and private sector through training and the development of manuals and guidelines.

3. Knowledge on labour-based works for employment generation is increased among decision makers and the general public.

4. Labour-based techniques and use of local resources is further researched and developed.

3.5.10 Conclusion

Labour-based technology has definitely taken hold in Uganda. The programme has been received with particular enthusiasm by the operatives. The labour based approach offers much needed extra income to the operatives, especially rural dwellers, and inculcates a sense of ownership resulting in a protective attitude towards the infrastructure.

The Uganda programmes have a very high level of funding by the government, which is increased gradually over the years. This augers well for the sustainability of the small scale contracting programmes. Indeed the implementation of the already declared privatisation programme of government will ensure more opportunities for the contracting private sector.
Implementation of the recommendations cited above would definitely improve on the quality and content of the future labour-based projects.

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4 TOOL AND EQUIPMENT PROCUREMENT
4.1 FEEDER ROADS PROJECT EASTERN PROVINCE, ZAMBIA: EXPERIENCES WITH PROCUREMENT OF EQUIPMENT AND HAND TOOLS FOR LABOUR-BASED ROAD MAINTENANCE AND REHABILITATION WORKS

Alfred Sakwiya, Feeder Roads Project, Ministry of Local Government and Housing, Zambia

4.1.1 Introduction

The Feeder Roads Project was requested to give a presentation on procurement. As we are no procurement specialists, but merely a project which recently procured equipment and handtools for its programme, we would like to share those experiences with you. Before going into procurement issues, we would briefly like to introduce the Feeder Roads Project to you.

4.1.1.1 Project's Immediate Objectives

1. Develop capacity of district councils to plan, design, implement and manage road rehabilitation and maintenance works by small scale labour-based contractors.
2. Develop a private sector construction industry capable of rehabilitating and maintaining feeder roads using labour based methods.
3. Improve access to project areas.
4. Create direct employment.

4.1.1.2 Project's budget

<table>
<thead>
<tr>
<th>Donor</th>
<th>Purpose</th>
<th>US$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRZ</td>
<td>Running of Contract Management Units and Maintenance Funds</td>
<td>1,042,400</td>
</tr>
<tr>
<td>UNDP</td>
<td>Technical Assistance and Training</td>
<td>1,244,832</td>
</tr>
<tr>
<td>UNCDF</td>
<td>Rehabilitation Funds and Equipment</td>
<td>4,636,512</td>
</tr>
</tbody>
</table>

Project Total: 6,923,744.

4.1.1.3 Project's expected outputs

1. District staff trained in planning, design and management of R&M contracts.
2. Supervisory staff trained in effective supervision and inspection of R&M contracts.

3. Maintenance programmes established and under implementation.

4. An efficient system for contract management tested and established, including a monitoring and reporting system.

5. Two National Engineers trained to manage labour-based rehabilitation and maintenance programmes.

6. Selection procedures for potential contractors developed.

7. Nine small scale rehabilitation and 25 small scale maintenance contractors developed to operate as labour based R&M enterprises.

8. Approximately 500 km of road rehabilitated and approximately 700 kms under a regular maintenance programme by contract using LB methods.

9. A total of approximately 900,000 worker days of direct employment generated during rehabilitation and maintenance contracts.

4.1.1.4 Project’s progress to date

1. Fifteen maintenance contractors trained and effective.

2. Ten rehabilitation contractors trained.

3. US$ 800,000.- of equipment procured and issued. (A Credit Firm is being engaged to recover these funds from the contractors, to be re-invested in rehabilitation)

4. 14 council supervisors, seven districts under training.

5. 21 km of road rehabilitated.

6. 60 km of road maintained.

7. 70 km of rehabilitation contracts prepared.

8. 190 km of maintenance contracts prepared.

9. 15,000 worker days generated on maintenance works.

10. 30,000 worker days generated on rehabilitation works.

4.1.2 Procurement

The project had four main purposes for which procurement was required:

- Equipment for district staff to design, prepare, manage labour based contracts.
- Handtools for maintenance and rehabilitation contractors.
- Equipment for rehabilitation contractors.
- Equipment, tools, etc. for the project office.
In all four cases the exact requirements had to be defined. Requirements are partly dictated by the project document (work programme and budget), and partly by knowledge and expertise of project staff.

To implement the procurement, the project had a number of options available, each of them having their own regulations with regards to procurement procedures:

- through the executing agency, in this case the Ministry of Local Government & Housing.
- through the financing or co-operating agency (UNDP and ILO).
- through IAPSO (UN Procurement Agency).
- through direct purchase in the project area.

A brief description will follow for each purpose for which the project has procured equipment.

### 4.1.3 Equipment for District Staff to Design, Prepare and Manage Labour-based Contracts.

The shift from force account implementation of roadworks to implementation by private contractors is only possible by training contractors, and in recent years attention went mainly to develop contractor capacity to make sure that road maintenance and rehabilitation works were carried out in a professional way. However, to enable this shift successfully to be made, the capacity of the district councils to plan, design, and manage contracts needs to be enhanced. An enabling environment within the Director of Works (DoW) departments (eight in total) need to be established to ensure proper supervision and management of the contractors. This is being addressed by the project as follows:

After an inventory of existing assets within the DoW departments (which was basically nothing), a schedule of requirements was prepared in a meeting with the DoWs. The requirements consisted of survey equipment, soil testing equipment, office equipment and transport equipment. Although certain items like stationary could be bought locally, most items like level instruments, measuring wheels, copiers and computers are cheaper abroad and therefore it was decided to facilitate the procurement through IAPSO. After submitting the request for a quotation, the same was received two weeks later. The project is now in a phase to gather more information from IAPSO on the offered items to ensure that the correct items will be purchased. Once agreement is reached on the order, the project will ask the Ministry to prepare a Request for Direct Payment, to be submitted to the UNDP. Once this is done, the order can be placed.

The preparation of the schedule of requirements has proven to be the most difficult and time consuming part of the process. Equipment and tools for planning, surveying, preparing and managing contracts is not well addressed in the ‘ILO Guide to Tools and Equipment’ (The Guide). The section on surveying equipment is mostly considered unprofessional and therefore unacceptable. The Guide does not give information on soil testing equipment. In view of this experience the project recommends as follows:
**Recommendation 1:** The Guide to be revised to include engineering survey equipment and soil testing equipment for all tests required.

**Recommendation 2:** Check lists to be prepared to ensure that clients will be equipped with the correct tools and equipment to enable them to do a good job.

**Recommendation 3:** Identification of manufacturers and suppliers of survey and soil testing equipment in different project areas, information which should be updated on a regular basis.

### 4.1.4 Handtools for Maintenance and Rehabilitation Contractors

The maintenance contractors are only equipped with handtools and these were procured by the UNDP before the start of the project with the assistance of the Roads Training School in Lusaka, and were available in the project area. The procurement of handtools for the rehabilitation contractors was implemented by the Project and started in January 1997 with the preparation of a schedule of requirements. For the schedule of requirements, the project relied on expertise within the its personnel, the guide and documents and reports of other projects. Taking into account the monthly expected output per contractor, a decision was taken on the quantities for each item. With regard, to technical specifications, detailed descriptions were provided only if further identification of the tool was required. The most important specification given was to supply good quality handtools. The suppliers were instructed to mention the manufacturer of each item in their quote.

The next step in the process was to identify possible manufacturers of handtools in the project area. A manufacturer of hoes, slashers and bush knives was found in Blantyre, for the rest, only commercial suppliers of imported handtools were available in Zambia. From previous experience, a number of reliable suppliers were invited to prepare and submit a quotation. A number of suppliers came back for further information on a few items.

After receiving the quotations, an evaluation was prepared and the project asked the Ministry to prepare a Request for Direct Payment, to be submitted to the UNDP. The order was confirmed and the handtools arrived in the project area six weeks later.

Of the total order (approximately US$ 50,000), about US$ 7,000 (15%) had to be withheld for wrong deliveries. Plastic watering cans were delivered instead of steel ones. Small garden rakes were delivered instead of soil spreaders. Plain pine wood in 6m length was delivered instead of boning rods. The supplier has promised to correct the wrong deliveries.

The total period to procure the hand tools, from preparation of schedule of requirements until delivery in the project area was approximately three months.

The Guide gives very detailed information and specifications on a number of hand tools. However, those detailed specifications are mainly important in the manufacturing process of the handtool and cannot help much in a procurement process. Budget and time rarely allow a project to go into development of manufacturing capacity of handtools in the area of operation, it must depend on
ready available products. Professional production of the larger variety of handtools requires expertise and large investments.

**Recommendation 4:** The Guide to be updated to identify manufacturers of good quality handtools in different project areas and more information should be readily made available to projects on sources for communication (tel/fax/email).

### 4.1.5 Equipment for Rehabilitation contractors.

The procurement of rehabilitation equipment has been an important challenge for the project, and the main concern was timely arrival to allow the contractors to start work in the field as soon as they came out of the formal training phase. However, procurement could not start before the signing of the project document. The items to be procured per contractor were the following: two tractors, three trailers, one waterbowser, one waterpump, one vibrating pedestrian roller, one tractor towed roller, one vanette 4WD pickup. The whole package was estimated at US$ 120,000.

With regard to the tractors, it was first established which models were already available in the project area, which would minimise spares supply and servicing problems and, after this was established, that particular brand was specified in the schedule of requirements. Procurement procedures proved to be flexible enough to do this. The same applied to the pedestrian vibrating rollers, and a particular model was specified in the schedule of requirements.

With regard to trailers, water bowsers and tractor towed steel drum rollers, the project attempted to source local manufacturers in the country and it concentrated its search mainly in the Lusaka area which is 600km away from the project area. The drawings of the Kenyan trailer proved to be very helpful during discussions and negotiations, however, such specifications did not exist in the case of water bowsers and rollers. Together with the identified workshop, basic measurements were taken from rollers developed by and in use at the Roads Training School, and modified to arrive at a final design. The workshop had never made the Kenyan type of trailers, secondly, they did not have enough capacity to manufacture all the required trailers (21), and it was therefore decided to order only seven trailers and seven rollers with the workshop, while the balance of the requirements were ordered from a well known manufacturer of trailers and water bowsers in a neighbouring country. Because of the absence of proper drawings for the rollers, close supervision of the manufacturing process was required by the project, which was not easy to arrange. With regard to implements like trailers, rollers, water bowsers and culvert moulds, local manufacturing should be strongly encouraged, provided that quality can be assured.

In procuring such large quantities of equipment, it is very important to be aware of certain regulations in procurement procedures. In our case, for example, the tractor order passed the US$100,000 rule which implied that the tender board of UNCDF New York had to be involved, taking a long time to approval. Eventually, all equipment arrived in the project area in time to start the field work.

**Recommendation 5:** Detailed construction drawings be prepared and agreed for water bowsers, steel drum rollers and culvert moulds. Drawings should include a breakdown of elements and practical tips for the manufacturing process. Reports to be published as attachments to The Guide.
Recommendation 6: In the case of equipment, addresses and contacts of manufacturers, workshops and branch offices per country or region need to be updated.

Recommendation 7: Procurement regulations to be described in a practical way to allow for proper planning.

In general, the Feeder Roads Project did not encounter severe problems with the procurement of equipment and handtools. Handtools were procured within three months time and all equipment required by the project arrived in the project area approximately half a year after the procurement process was initiated.

However, with this paper, we hope we were able to present a number of problems which will provide sufficient basis to stimulate a discussion during the seminar.
4.2 EQUIPMENT PROCUREMENT FOR THE DNEP/DFID FEEDER ROADS PROJECT, MOZAMBIQUE

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Synopsis

This paper provides an account of the procurement of equipment for the DNEP/DFID Feeder Roads Project in Zambézia Province, Mozambique. An outline is provided of the procurement process, mainly from the in-country point of view. Measures that have been taken for clearing the equipment through Mozambique customs are described.

The objectives of the project include: the rehabilitation of tertiary roads in Zambézia Province in order to improve the economic and social prosperity of the local population, and the development of capacity in the local road construction industry. The project is being implemented by the National Directorate of Roads and Bridges (DNEP), with support from consultants. Execution of the works is by emergent, small-scale contractors who are receiving training within the project.

The equipment supplied to the project includes tractors and trailers, towed water bowsers, pedestrian rollers, towed rollers, Land Rover pick-ups, seven tonne flatbed trucks and many other smaller items. The equipment has been procured, mainly in the United Kingdom, in accordance with the requirements of the Department for International Development (DFID). It is being delivered by sea to the port of Quelimane in Zambézia Province.

The Mozambique Government has been able to fulfil its commitment to pay the import duties. This has resulted in relatively few problems with clearance of the equipment through customs in Quelimane. The consultants have provided support to DNEP for the co-ordination of in-country aspects of the importation of the equipment at a local and national level.

4.2.1 Background to the Project

The purpose of the DNEP/DFID Feeder Roads Project is to rehabilitate approximately 800km of existing classified feeder roads in Zambézia Province, Mozambique. This is in order to improve the economic and social condition of the local population. The project is being implemented by the Mozambique National Directorate of Roads and Bridges (DNEP) through DEP Zambézia, the Provincial Department of Roads and Bridges. Support to DNEP and DEP for the management of the project is being provided by consultants.

The project is being funded by the British Government, through the Department for International Development (DFID), for the purchase of equipment, materials, works execution and the consultants. In addition, DFID are funding upgrading of accommodation, some road maintenance (within the project period) and
The Government of Mozambique contribution includes the payment of import duties, DEP supervision of the works, offices and housing for the consultants, and in-country training.

The project is part of DNEP’s Feeder Roads Programme, which in turn is part of the World Bank-supported Roads and Coastal Shipping Project (ROCS), which seeks to ultimately rehabilitate the majority of the classified road network in Mozambique.

Preparations for the implementation of the project started in September 1995 in order to facilitate the commencement of site operations after the 1995-1996 rains. The project completion date is 15 September 2000.

By the end of July 1997, approximately 60 kilometres of road had been rehabilitated to all-weather standard and 40 kilometres were under routine maintenance. Six contractors are currently working independently on different sites in Mocuba and Ilé districts under the supervision of the Provincial Department of Roads and Bridges (DEP), and with continued support from the Consultants.

The equipment supplied to the project is relatively sophisticated for a labour-based project. It includes tractors and trailers, towed water bowsers, pedestrian rollers, towed rollers, Land Rover pick-ups, seven tonne flat-bed trucks and many other smaller items. Most of the equipment is provided to enable gravelling operations and for compaction. It is anticipated that gravelling will be required on up to 50% of the project roads.

The equipment has been procured in accordance with the requirements of the Department for International Development. Most items have been supplied from the United Kingdom and are being delivered by sea to the port of Quelimane in Zambézia Province. The total budget for procurement of equipment is about US$3,000,000.

The contractors are hiring the equipment from DNEP at rates calculated to represent the full cost of owning and maintaining equipment. Payment is made through deductions from the monthly payment certificates. DNEP is currently preparing proposals to the Ministry of Finance to allow it to enter into hire-purchase contracts with the contractors for the sale of specific items.

The contractors will be encouraged to purchase equipment in accordance with their management capacity in order to avoid over-capitalisation through the purchase of assets that may be surplus to their requirements. Future work opportunities, beyond the end of the project, will likely be confined to routine maintenance contracts.

Items of equipment that are not purchased by contractors will be kept centrally and will be available for hire for the duration of the project. At the end of the project, DNEP will either dispose of the surplus equipment, or continue to make it available for hire.

To date all items for the first consignment have been received in the port of Quelimane and have been cleared through customs for use on site. The ordering and delivery of items from the second consignment has commenced, in
accordance with the site requirements, and some items from the second consignment have been received.

4.2.2 Procurement of Equipment

The procurement of equipment for use on the project is being done by the consultants through an associated company. This company is a registered procurement agent with the British Government Procurement Advisory Monitoring Unit (PAMU)\textsuperscript{14}.

The use of in-house procurement capability has benefited the project in various ways:

1. Good lines of communication and a close understanding have developed between the procurement advisor in the United Kingdom and the project advisor in the field. This has enabled prioritisation of the procurement activities and the adjustment of specifications to suit site requirements. The project has, as a result, been able to meet programme deadlines.

2. Staff of the consultant travelling to southern Africa, often on other projects, have been able to carry urgently required documents and small items of equipment and spare parts.

The procurement process has been relatively complicated, as demonstrated in the flow chart given in Figure I.

The process started with the preparation of the equipment list. The list was prepared by the consultants on the basis of the requirements of the project appraisal and was approved by DNEP and the DFID. The equipment specifications were based on the standard equipment specified for the Feeder Roads Programme brigades. The quantity of each item was calculated on the assumption that some contractors would develop larger operations than others, and would therefore require, and be able to afford, more equipment.

The equipment has been ordered in two main consignments. This was in order to reduce the risk of over-supply in the event that it would not be possible to find enough contractors to participate in the project. The first orders were placed in May 1996, and most of the equipment from the first consignment was operational on site before the end of 1996.

The selection of suppliers was done on a competitive basis in accordance with the requirements of the PAMU. The technical evaluation of the bids received from the tenderers was done on site by the consultants mechanical technician and the project advisor. Technical considerations included: availability of spare parts and agent back-up locally or in the region; standardisation of parts where possible, and experience of durability and suitability from similar projects in Africa. The financial evaluation was done by the procurement advisor in the United Kingdom. The final appointment was made with reference to the technical and financial evaluations in accordance with PAMU’s requirements.

\textsuperscript{14} Soon to be renamed “Procurement, Policy and Practice Unit”.

Some urgently required items were purchased in the region. This included: vehicles for the consultant’s supervision staff; some tractors and trailers; handtools, and; building materials for use in the rehabilitation of housing for the consultant. The local procurement resulted in some additional costs, but was necessary in order to commence implementation of the training site ahead of the arrival of the bulk of the equipment from the United Kingdom.

In order to minimise transport costs, suppliers of small items have supplied their goods CIF (Carriage in Freight) to a container terminal in the United Kingdom. Shipping to Mozambique has been arranged by the procurement agent, who has co-ordinated the supply of goods to the terminal, to ensure that containers are full when they are dispatched. Shipping to Quelimane has been done via the South African port of Durban.

The importation and clearance of the equipment has been initiated and managed on behalf of DNEP by the consultant's project team based in Quelimane. The importation process includes: production of the import permit; clarification of queries from the inspection agents; arranging inspection of the goods by Customs on arrival; temporary storage in Quelimane before deployment to the sites; registration and insuring of vehicles; transport to site. The key to the success of the process has been the local recruitment of a Mozambican expediter, with a thorough knowledge of Quelimane, and some experience in dealing with the various agencies involved in the process of importation. The decision to manage the process at a local level has been critical to its success.

The payment of import duty for the clearance of the goods is the responsibility of the Government of Mozambique, through the National Directorate of Roads and Bridges (DNEP), who are the owners of the equipment. DNEP’s capacity for dealing with large consignments of imported equipment is now well developed, following many years of experience, and the clearance of the goods has been relatively trouble-free. Delays that have occurred have largely been due to the lack of capacity in the parastatal clearing agent, ADENA (Agência Nacional de Despacho) and in Customs to deal with the sheer volume of paperwork that has been generated.

Project funds have been used for payment for services provided in Quelimane, such as the production of the import permits, port charges, and the licensing and insuring of equipment following customs clearance. This has been a considerable advantage in reducing delays in the deployment of equipment on the sites.

Typical bureaucratic problems that have been encountered in the procurement process include:

1. The preparation of documentation for the importation of some items, such as, the mechanic’s tools and equipment, was delayed for several months in Mozambique due to the large number of items, and the complexity of the descriptions of the goods which had to be translated into Portuguese. The government department (Ministério da Indústria, Comércio e Turismo) approving the import permits in Quelimane initially insisted that all items should be listed individually on the permit. This requirement was eventually abandoned following advice from Maputo that items with the same
identification code can be grouped on the license, as long as they are listed separately on the supplier’s proforma invoice.

2. Trailers imported from Zimbabwe were to be transported from Harare by rail to the Mozambique port of Beira, and then by ship to Quelimane. This is the cheapest transport route from Harare to Quelimane for bulk goods. On arrival in Beira, the trailers were impounded by customs who demanded clearance of the trailers before they could be transported to Quelimane. The shipping agent employed by the supplier inadvertently gave the shipping documents to a commercial clearing agent who initiated the clearance process. Since all goods imported by the Mozambique government must be cleared by ADENA (the parastatal clearing agent), the commercial agent was not in a position to clear the goods. By the time the problem had been identified, and the documents retrieved from the commercial agent and passed on to ADENA, several months of delay had occurred.

Meanwhile, the Clean Report of Findings (CROF) certificate issued by the inspection agency was sent in error to Customs in Maputo who apparently lost it. This error caused a further delay of several months as Customs, and the inspection agent, searched for the document. Production of a duplicate copy would have required a specific letter of request from DNEP. Eventually, the CROF was located and forwarded through Quelimane to ADENA in Beira, who were able to clear the goods.

Other consignments of goods imported for the project from Zimbabwe have been transported by road through Malawi, and have entered Zambézia at the Milange border. Control of the Milange border post is the responsibility of customs in Quelimane. It has thus been possible for the consultant, who has a permanent presence in Quelimane, to facilitate and co-ordinate the clearance process. Few problem have been experienced.

3. The office of Agência Nacional de Despacho CADENA) in Quelimane has, at times, been overwhelmed by the volume of paperwork received from ADENA in Maputo. This is due to the large number of different items imported for the project, and has led to long delays in clearing specific items. For example, heavy duty tow hitches for the tractors were held in the port for several months while ADENA apparently waited for clearance documents from Maputo. When the documents finally emerged, it was apparent that they had been in the office of ADENA in Quelimane for about six months.

The consultant’s expediter in Quelimane is now involved in assisting ADENA to sort through paperwork in order to avoid similar problems from recurring.

4.2.3 Conclusion

The equipment specifications and quantities for the DNEP/DFID Feeder Roads Project have been designed to enable the project to attain its objectives in terms of output of rehabilitated road, and the development of capacity within the local road contractor industry. The equipment specified is similar to equipment supplied
to brigades within the national Feeder Roads Programme, but the quantities have been adjusted to meet the requirements of private contractors.

The equipment is owned by DNEP who lease it to the contractors at rates that reflect the full purchase price. The contractors will ultimately have the opportunity to enter hire-purchase agreements with DNEP for the purchase of specific items. The opportunity to own equipment is a major motivator for the contractors, and provides them with a means to invest in capital assets. This is essential for the growth of a small business.

The procurement of equipment is being done by the consultants in accordance with the requirements of the British Government PAMU. The use of in-house capacity has allowed flexibility in the procurement programme to suit site requirements, and the project has benefited from group commitment to meeting programme deadlines.

Bureaucratic delays in the clearance of equipment in-country have largely been overcome through prompt payment of import duties by the DNEP, and pro-active support by the consultants for the co-ordination of the process. The availability of project funds and management capacity at a local level have been significant in facilitating the movement of goods through Quelimane port and onto the sites.
Figure I: Procurement Process

**In the United Kingdom**

1. Agree equipment list
2. Prioritise items
3. Prepare tenders
4. Answer queries from tenderers
5. Revise specifications
6. Evaluate tenders
7. Appoint supplier (issue Order)
8. Obtain proforma invoice from supplier
9. Co-ordinate inspection of the goods before shipping.
10. Arrange packing of containers at the UK container terminal.
11. Final payment made to supplier.

**In Mozambique**

1. Input from site and specialist advisors
2. Site programme of works
3. Input from site and specialist advisors
4. Technical evaluation
5. DNEP "no-objection"
6. Apply for import permit
7. DNEP uses import permit to obtain proforma invoice from ADENA for the payment of duty
8. Ensure passage of import permit through inspection agency offices in Quelimane and Maputo to UK
9. DNEP forwards the ADENA proforma to the Min. of Finance
10. Arrival of goods in Quelimane
11. Min. of Finance issue certificate proving payment to ADENA Maputo
12. Customs inspection, registration, insurance and deployment to site.
13. ADENA Maputo send documents to ADENA Quelimane
5 ROAD CONSTRUCTION AND MAINTENANCE
5.1 REHABILITATING AND MAINTAINING SURFACED ROADS

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5.1.1 Introduction

The South African Department of Transport (SADOT) has recently published a series of manuals prepared by the Division of Roads and Transport Technology of the CSIR which are designed to teach student trainees the art of maintaining and upgrading streets using labour-based methods. The manuals were based on a pilot project undertaken in Phuthaditjhaba in the North-Eastern Free State where various maintenance and upgrading techniques were tested as part of a community training program.

This paper will focus on the labour-based upgrading methodologies used in Phuthaditjhaba and fully described in manual 7 of the series. The manual describes techniques that can be used to upgrade existing gravel streets, using the existing structure as a subbase, where traffic volumes are below 500 vehicles per day, with less than 10% of these being heavy trucks.

5.1.2 Geometrics

Generally speaking, the roadworks in townships have been constructed to grade and crossfall and the houses are normally constructed in a straight line. A number of methods can be used to establish the centre line of an existing street, including:

a) boundary beacons;
b) the fence lines/boundary lines if uniformly constructed, as shown in Figure 1. However, fence lines are not always correct, thus making this method unreliable and inaccurate;
c) the houses, if these are set out in straight lines;
d) the best line that can be established from the electricity poles;
e) the best line that can be established from the existing gravel road, taking into account the fronts of the houses.
Once the centre line has been established, using ranging rods, the edge of the street can established by placing steel pegs at 10m intervals, 400 mm above the existing ground.

In the pilot project, the pegs were placed on the edge of the topside of the crossfall of the street, in order to construct an open drain on the topside of the crossfall. To reduce the earthworks to a minimum, a "rolling grade" was established by tying a white sisal string line to the tops of the steel pegs. This "line" was adjusted by eye by lowering or raising the pegs to give a smooth rolling grade line.

Once the rolling grade line had been established, reference pegs were placed exactly 400 mm below the top of the adjusted steel pegs (rolling grade line). See Figure 2.
5.1.3 Drainage

For township drainage it is essential that, prior to surfacing the road, the main stormwater spinal drainage is in place. In this case, the outfall main stormwater drainage was in place.

It was decided to use an open drainage system as this obviated the problem of blocked stormwater drains in townships.

Steel templates were placed every 2m, care being taken to place these templates accurately, as the top of the open drainage system on the edge of the road would form a reference line for construction and preparation of the subgrade.

Concrete was cast in alternate bays using light reinforced mesh only on the leg of the side drain closest to the road. Originally, the concrete was mixed by hand as part of the training, but to expedite the work, a small concrete mixer was used on the latter part of the works.

On relatively flat slopes, the levels, as set out above, were checked with a dumpy level to ensure that sufficient fall had been obtained. It is recommended that where very flat slopes are encountered, this check be instituted.

5.1.4 Construction of Subbase

By selecting the appropriate crossfall, which can vary between 2% and approximately 2.8%, the amount of earthworks to be done with hand labour can be determined, using the final concrete level of the drain as reference points along the length of the road.

The top of the finished side drain served as a datum for establishing the levels of the opposite edge, which were obtained by transferring this level with a spirit level and a straight edge. The subgrade was levelled off to the required levels using picks and shovels. Wheelbarrows were used to cart the material to the fill areas. The subgrade/subbase was well compacted by the traffic prior to construction, but a BOMAG 65 pedestrian roller was used to compact the final earthworks and fill areas.
To expedite this work, the surface was well watered the previous day with a garden hose attached to the standpipe at one of the houses. It was also possible to stockpile some of the gravel obtained in the excavation for use at a later stage in the emulsion treated base.

It was most important to ensure that the levels of the subbase were as accurately constructed as possible, since that assisted with the laying of the steel shutters when the emulsion treated base was placed.

There were one or two minor areas which were clayey. These were treated by hand and compacted in situ.

5.1.5 Material Selection and Design

The in situ material was checked by carrying out a dynamic cone penetrometer (DCP) survey of the four streets involved. It was established that the cover corresponding to the in situ California Bearing Rations (CBR's) obtained from the DCPs was generally greater than that required in the old National Road 7,000lb. design curves. It was therefore decided to use a 100 mm thick base as this would be perfectly adequate for the type of traffic anticipated on these lightly trafficked streets.

From an economy point of view, it was necessary to use whatever local materials were available. The local material that was readily available at the time was a decomposed dolerite material.

The streets were also gravelled with decomposed dolerite. Tests were done, not only on the gravel on the streets, but also on gravel from the quarries, with a view to using this material with emulsion.

As the plasticity indices (PIs) of the gravel were all in excess of 10 (to 15), it was necessary to treat the material not only with emulsion, but with lime before application of the emulsion.

The amount of emulsion used was 2% of anionic stable grade emulsion, 1% of cement and 1% lime. The lime, cement and gravel were first mixed dry by hand, after which the diluted emulsion was applied.

The densities obtained in the field were in the order of 97% Mod. AASHTO density, which were obtained with a 65 BOMAG pedestrian roller.

The CBRs of the materials tested in the laboratory varied from 106 at 93.8% compaction to 290 at a compaction of 99.3%.

5.1.6 Method of Construction

5.1.6.1 Layout

Each street, with a road width of 3.5m, was split into half-widths of 1.75m.

The reason for this is that when very coarse material is used, it is onerous for labour to spread the material. The concrete side drain formed one continuous level to which the emulsion treated base had to be placed, the level on the other side being controlled by steel shuttering formed of 100 x 150 mm angle iron.
5.1.6.2 Materials

The emulsion used was anionic stable grade 60% bitumen emulsion, delivered to the site in 210 litre drums. The drums were rolled off the delivery truck onto steel or timber ramps to prevent any breakages and undue breaking of the emulsion in the drum. The drums were rolled backwards and forwards to ensure proper mixing of the emulsion before they were used, as the drums had been stockpiled on site, which causes the bitumen in the emulsion to settle to the bottom of the drum.

The drums were placed on a steel frame such as the one illustrated in Figure 3 and were fitted with a ball valve. The height of the steel frame was high enough to accommodate the measuring cylinders.

![Figure 3: Stand for drums of emulsion and typical measuring drums](image)

The ball valve allowed the control of emulsion into the measuring containers and to ensure a clean and neat operation with minimum wastage.

5.1.6.3 Blending

The quantities of cement and lime required per batch were measured with the measuring containers (see Figure 3). The ETB was mixed by hand and, in the latter part of the project, with a concrete mixer. The aggregate was delivered on site with a large amount of oversize and was then stockpiled as close as possible to the working area. The grading of the material was very coarse and to overcome this problem, coal forks were used from which the alternative tynes had been removed. This enabled the labour units to remove the coarse material, leaving relatively fine material for the work. The gravel was firstly mixed with cement and lime, followed by the diluted emulsion, up to 1:10, i.e. 1 part emulsion to 10 parts of water. The initial proportion of emulsion to water was 1:3 or 1:4. This was then checked to determine whether the water should be increased or reduced. The amount of water in the gravel was also taken into account as this affected the degree of dilution. The amount of liquid that was added to the mix was approximately 1 - 1.5% over the optimum moisture content required for the Mod. AASHTO density which had been obtained from the laboratory tests.
Measuring containers were essential to maintain accurate work for both aggregate and emulsion. The 25 litre cans were fitted with handles which made them user friendly. The 10 litre cans were used to measure the quantities of cement and lime.

### 5.1.7 Placing of ETB

The maximum depth of ETB that can be effectively compacted with the BOMAG 65 is 75 mm. As the thickness of the ETB layer was 100 mm, it was therefore necessary to place the ETB in two layers.

The first layer of ETB was placed level with the shuttering and the top of the drain. (i.e. for 100 mm base). Steel squeegees were used for levelling the mixed ETB as the rakes tended to cause the mix to segregate, which is not desirable, whereas steel squeegees distribute the material uniformly without segregation.

The second layer of ETB was placed level with the top of the gauges, which had been placed on top of the shuttering and drain. These ensured the uniformity of the constructed level of the final base. The steel screed was used to obtain the final levels of the ETB uniformly between the steel shuttering and the top of the side drain or that of the inside edge of the concrete gutter.

The surface was dampened with a light application of water to prevent it drying out prior to compaction. Normally four to six passes with the BOMAG 65 were required over the uncompacted material.

The emulsion treated base was placed in the box and screeded to the level of the top of the concrete and the top of the steel shuttering. Steel squeegees were used to spread the material ahead of the screed. Once some 8m of length of road had been placed, the pedestrian roller was used for compacting this material.

Once the first layer had been compacted, second layer of ETB was applied, using 25 x 25 mm box sections on top of the concrete and the steel shuttering. This was compacted with the BOMAG pedestrian roller, until the material had been compacted to the level of the concrete and steel shuttering, the box sections having been removed from the concrete and steel shuttering.

Before the second application of ETB was placed, the surface was treated with diluted emulsion in the ratio of 1 to 10, and on completion of the second layer, the surface was again treated with diluted emulsion in the ratio of 1 to 10 emulsion to water.

### 5.1.8 Advantages of Using the Emulsion Treated Base

There are several advantages to using emulsion treated base, apart from the strength that is obtained with the process:

a) As the work is done with hand labour, there is usually an extended period of time which elapses before the road is surfaced. The emulsion treated base is capable of carrying this traffic without surfacing for extended periods.

These streets were open to traffic for up to three to four months before surfacing was applied, without any damage of consequence to the surface.
b) There is no deterioration as far as cracking of the base is concerned.

c) The problems experienced when priming a base and waiting for it to cure and stopping the public from using the uncured primed base are obviated when an ETB is used, even if the surface has to be treated with diluted emulsion after extended periods of being used by traffic.

d) Should the surface be damaged mechanically, the base will not deteriorate and form potholes, as is the case with other unstabilised material or even crusher run material.

5.1.9 Surfacing

The object of this pilot scheme was to establish which surfacing would be the most economical and appropriate to apply by labour-based methods. Four types of surfacing were placed on four different streets, namely:

- a single seal
- a double seal
- a Cape seal, and
- a slurry seal.

In all cases where binder was sprayed on the road, a motorised hand sprayer as shown in Figure 4 was used.

![Motorised hand sprayer](image)

**Figure 4: Motorised hand sprayer**

Before any spraying could be done, it was necessary to establish the delivery rate of the spray pump. The rate of application of the binder was then controlled to within 10% using an enlarged manually-operated clock, controlled by the second hand of a wrist watch. The use of emulsion ensured that any errors in the quantities of the residual binder sprayed were reduced by some 35 to 40%.

i. Single seal

Students were instructed in how to use the ALD method for establishing the application rates of both binder and aggregate by using the pan and cylinder method for establishing the ALD and in the use of graphs to establish their prospective application rates for binder and aggregate. A 65% cationic bitumen emulsion and a 9.7mm aggregate were used for this single seal. Generally a maximum of 0.7 litres to 0.8litres of emulsion can be sprayed before the binder
tends to flow. For this reason, a tack coat was applied at 0.7 litres/m² and the 
aggregate neatly spread in a single layer by hand from small accurately measured 
heaps, spotted along the shoulder of the street. The surface was rolled and the 
balance of the binder sprayed as a penetration spray. Protective screens as 
shown in Figure 5 were used to ensure a neat edge line of the surface both for 
tack and penetration sprays. The final result was a sound and uniform surface, 
with no whip-off of aggregate.

![Figure 5: Protective screens](image)

The measuring containers (half drums) were used for spotting the aggregate 
along the constructed base to ensure accurate application rates of aggregate.

A manually operated clock was used in conjunction with the spray machine to 
apply the binder at required rates. The discharge rate of the spray machine was 
determined, the area to be covered with the binder was demarcated and the 
required time to cover such a section was then calculated. The spray operator 
had to finish that section in the required time. The chips were then applied by 
hand using shovels. The BOMAG roller, Figure 6, was used to roll the chips into 
the binder.

![Figure 6: BOMAG 76 roller](image)

### ii. Double seal

A double seal was constructed as above using a 13mm and a 6.7mm aggregate 
with cationic emulsion. To ensure minimum whip-off of aggregate the 13mm 
aggregate was choked with 6.7mm aggregate to obtain a tightly knitted surface 
before the penetration spray was applied. The 6.7mm aggregate was uniformly 
applied in a single layer and well rolled before a final fog spray was applied. The
quantity of binder required after application of the tack coat was split between the penetration spray and the fogspray. The final result was sound and the seal was found to be suited to labour-based application if well controlled. A double seal is probably the most difficult seal to apply efficiently with hand labour as much of its success depends on experience in the efficient use of rollers.

iii. Cape seal

The Cape seal consisted of a 13 mm aggregate applied in a similar manner as in the single seal, using a cationic emulsion as the binder in the tack coat and penetration sprays. A slurry seal was applied which filled all the voids in the 13 mm single seal. This was dragged with a hessian drag and rolled. The final result was sound and uniform and the seal was found to be user-friendly for labour-based work. A Cape seal is a strong, tough seal and could well be used on bus routes and on more heavily trafficked roads.

iv. Slurry seal

10mm slurry (wet) was applied, using a medium-graded aggregate and a stable grade anionic emulsion. 10 mm steel guide rails were used to ensure consistent application of the 10 mm slurry.

Any high spots on the base were rectified by hand chipping to ensure that the required thickness of slurry was obtained. The final result was sound and uniform and the process was found to be user-friendly for labour-intensive work. Before the slurry was applied, the surface was cleaned and treated with diluted emulsion in the ratio of 1 part of emulsion to 10 of water.

In all cases where binder was sprayed on the road, a motorised hand sprayer was used.

Before any spraying could be done, it was necessary to establish the delivery rate of the spray pump. The rate of application of the binder was then controlled to within 10% using an enlarged manually-operated clock, controlled by the second hand of a wrist watch. By using emulsion, any errors in nett residual binder sprayed were reduced by some 35 to 40%.

Acknowledgements

A number of participants from the public and private sector contributed financially, either directly or indirectly, to the pilot project and to the production of the manuals. These included:

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- Quickfix Manufacturing;
- The Southern African Bitumen and Tar association (SABITA);
- TOSAS;
- V.I. Instruments.

Their support and encouragement is gratefully acknowledged.
5.2 HIGHWAY MAINTENANCE MANAGEMENT

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Zimbabwe

Summary

The paper emphasises the importance of timely and scrupulous maintenance of highways and discusses some of direct consequences of failure to follow the normal maintenance procedure. The paper analyses typical routine and recurrent maintenance activities and shows how the critical path method can be used to model such projects.

5.2.1 Introduction

Every construction project has distinct stages which collectively constitute the project cycle. Some of these stages are identification, designing, tendering, construction, commissioning and maintenance. At the identification stage, the field technical personnel collect and study details of prospective projects and come up with projects which are economically viable. Therefore, projects with high benefit/cost ratios are short listed for designs to be produced. The projects then go for tender, when successful contractors enter into contract to execute them. The completed project is finally commissioned for use. At the commissioning stage, the future performance of the project is evaluated and the strategy for maintenance and repair is considered. Each phase of the project cycle is important. If, for example, the construction process has not been properly supervised and sub-standard materials have been used, the project may not last its design life no matter how good the subsequent maintenance strategy. The Overseas Unit of Transport and Road Research Laboratory has (1981) classified the three main functions of highway maintenance as follows:

1. To reduce the rate of deterioration and thus prolong its life.
2. To lower the costs of operating vehicles on the road by providing good running surfaces.

Highway maintenance therefore basically serves to improve the flow of traffic, conserves the assets represented by the roads, promotes the safety and comfort of road users, and preserves the aesthetic appearance of the roads. Failure to carry out regular maintenance of the road results not only in premature deterioration of the facilities, accident rates are also likely to increase drastically.

5.2.2 Maintenance Activities

Maintenance activities consist of routine, recurrent and periodic activities. Routine maintenance activities are those operations that will be required whatever the engineering characteristics of the road or the density of traffic it carries. Routine maintenance activities include grass-cutting, drain clearing, re-cutting ditches,
culvert maintenance, bridge maintenance and road signs maintenance. The recurrent activities may be carried out at intervals throughout the year; the frequency depends upon the volume of traffic using the highway. Some typical recurrent activities are pothole patching, surface repairs, edge repairs, sealing cracks and road surface marking. Periodic maintenance activities may include regravelling (for unpaved roads) and surface dressing/rescaling (for paved roads). These activities are needed after intervals of several years.

Robinson (1988) has given suitable definitions for some common terms such as upgrading, stage construction and rehabilitation. Upgrading aims at providing additional capacity when a road is nearing the end of its design life or because there has been an unforeseen change in use of the road. Typical examples of upgrading projects are the paving of gravel roads, the provision of strengthening overlays for paved roads and the widening of roads. Stage construction consists of planned improvements to the initial pavement standards of a road at predetermined stages throughout the project life. Stage construction differs from upgrading in that any later improvements are planned from the onset. Rehabilitation is needed if the road has deteriorated beyond the condition at which overlaying is a satisfactory engineering alternative. This is the normal result where the road has not received sufficient maintenance. Reconstruction to provide a new alignment should be considered as an upgrading project.

5.2.3 Economics of Maintenance activities

Roads will continue to deteriorate with time, even with adequate maintenance, until the design has elapsed, when the need for strengthening overlay or reconstruction becomes necessary. The need for efficient and regular maintenance operations become obvious if the data contained in Table 1 is critically examined:

<table>
<thead>
<tr>
<th>Maintenance activity</th>
<th>Cost US$/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routine and recurrent maintenance</td>
<td>500</td>
</tr>
<tr>
<td>Periodic reseal (after 5 years)</td>
<td>12,000</td>
</tr>
<tr>
<td>Overlay (after 10 years)</td>
<td>42,000</td>
</tr>
<tr>
<td>Regravelling</td>
<td>--</td>
</tr>
<tr>
<td>Reconstruction</td>
<td>175,000</td>
</tr>
<tr>
<td>Annual maintenance cost</td>
<td>6,000</td>
</tr>
<tr>
<td>(undiscounted apportioned over 10 years)</td>
<td>2,500</td>
</tr>
<tr>
<td>New construction</td>
<td>250,000</td>
</tr>
<tr>
<td></td>
<td>120,000</td>
</tr>
</tbody>
</table>

Source: Faiz and Harral (1987)

If the required routine and recurrent maintenance activities are not carried out, drainage will be ineffective and surface defects will worsen, thereby resulting in
water penetrating into the pavement structure. For a paved road, the consequences of the neglected maintenance activity will prematurely cause the need for a periodic maintenance which (from Table 1) will cost approximately 24 times more than the normal routine/recurrent maintenance operation. If the periodic maintenance activity is also delayed, a major upgrading activity (overlay) which is about three times more expensive than the periodic maintenance operation, soon becomes necessary. In the case of most developing countries, the problem is twofold: while the maintenance funds are insufficient, the bulk of the funds is diverted and spent instead on new construction. Maintenance operations cannot therefore be stretched to cover all the road networks.

5.2.4 Maintenance Management Procedure

A typical maintenance management procedure may consist of the following process (Robinson 1986, Robinson 1988): (i) inventory, (ii) inspection, (iii) maintenance needs, (iv) costing, (v) priorities, (vi) execution and (vii) monitoring. The inventory process establishes the basic reference for planning and carrying out maintenance and inspections. Since funds are not sufficient to cover all the road networks, it is necessary to establish priorities in order to determine which should be undertaken and which should be deferred.

The road should be inspected during the dry season and also during the wet season. The main purpose of the inspection is to identify the causes of defects so that maintenance operations can be planned to remedy them. The frequency and extent of carriageway and shoulder maintenance are closely related to the nature and volume of traffic on the road. A knowledge of traffic loadings will not only indicate which roads are likely to deteriorate most quickly but will also assist in establishing priorities. Therefore traffic counts should be undertaken to provide an estimate of annual average daily traffic (ADT).

5.2.5 Direct Labour/Contract Works

Maintenance activities must be properly planned so that they can be completed on schedule. Critical path method provides one method for modelling projects. The method may be outlined as follows:

i. Determine sequence of operations and activities that may be executed simultaneously, e.g., materials ordered must arrive before repair activities can start.

ii. Determine the duration of activities. By using performance standards (Overseas Road Note 1, Table 8) and suitable allocation of resources e.g., labour, equipment etc., the duration of each activity can be determined.

iii. 'Forward Pass' determines the Earliest Event Times while

iv. 'Backward Pass' determines the Latest Event Times. (see Figure 1.)

v. The 'floats' have been determined and tabulated in Table 1. Float indicates the range within which the start and finish times of an activity may vary without affecting the completion time of the project.

References

Transport and Road Research Laboratory (1983). *Maintenance management for District Engineers*. Overseas Road Note 1, Transport and Road Research Laboratory, Crowthorne.


### Table 1: Analysis of network diagram: Highway maintenance

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration (days)</th>
<th>Earliest event times</th>
<th>Latest event times</th>
<th>Floats</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start</td>
<td>Finish</td>
<td>Start</td>
<td>Finish</td>
<td>Total</td>
</tr>
<tr>
<td>1 - 3</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>3 - 5</td>
<td>7</td>
<td>14</td>
<td>14</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>5 - 7</td>
<td>7</td>
<td>21</td>
<td>21</td>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>7 - 10</td>
<td>15</td>
<td>28</td>
<td>28</td>
<td>43</td>
<td>0</td>
</tr>
<tr>
<td>10 - 11</td>
<td>10</td>
<td>43</td>
<td>43</td>
<td>53</td>
<td>0</td>
</tr>
<tr>
<td>11 - 12</td>
<td>7</td>
<td>53</td>
<td>53</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>1 - 2</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>2 - 6</td>
<td>10</td>
<td>10</td>
<td>18</td>
<td>28</td>
<td>8</td>
</tr>
<tr>
<td>1 - 4</td>
<td>10</td>
<td>0</td>
<td>11</td>
<td>21</td>
<td>11</td>
</tr>
<tr>
<td>4 - 8</td>
<td>14</td>
<td>10</td>
<td>21</td>
<td>35</td>
<td>11</td>
</tr>
<tr>
<td>8 - 9</td>
<td>8</td>
<td>24</td>
<td>35</td>
<td>43</td>
<td>11</td>
</tr>
</tbody>
</table>

**Notes:**
1. **Total Float** = Latest Date - Earliest Date - Job Duration (event B) (event A) (activity A-B)
2. **Free Float** = Latest Date - Latest Date - Job Duration (event B) (event A) (activity A-B)
3. Critical activities have no float while non-critical activities have floats.
5.3 MANAGEMENT OF SOME SELECTED LABOUR-BASED HIGHWAY CONSTRUCTION ACTIVITIES

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Summary
This paper discusses some of the ideal conditions which make a labour-based method of construction an acceptable option. A typical highway construction project is analysed in order to determine its component activities and their sequential relationships. The activities are then critically examined; those which may be executed by plant-intensive operations are separated from those which are best executed by labour-based methods under the local conditions. Simple methods of developing and analysing network diagrams are illustrated. Examples of methods of applying labour constants for construction activities are given. The need for using realistic labour constants is emphasised.

5.3.1 Introduction
Highway construction activities tend to be highly plant-intensive. Plant-intensive methods of construction can be effectively controlled so as to increase the outputs in order to reduce the project construction duration. Plant requirements for a highway project depend upon the size, type and location of the project. While a number of items of sophisticated equipment will be needed for the construction of an urban motorway, or an airport with a rigid pavement, very little equipment will be required for the construction of a secondary or feeder road, which will normally be designed to meet the requirements of low-volume roads in most developing countries. Labour-based methods of construction can still be introduced to reduce further the level of plant requirement. Most developing countries face severe shortages of foreign exchange, which is needed for the importation of construction equipment.

At the same time, unemployment is a major national issue. It is therefore safe to conclude that a possible solution to these problems would be to train some of the rural folk (who constitute over 60% of the population in most cases) to participate in labour-based construction activities. While conserving scarce foreign exchange, the problem of unemployment will also be redressed.

Planning, organising, directing, co-ordinating and controlling are some of the most important management functions. At the planning stage, the project manager literally breaks the project up into minute details in an attempt to identify all the activities that must be executed in order to complete the project. The sequence of operations and the inter-relationships between activities must also be determined.
The 'directing' function is concerned with training subordinates to carry out assigned tasks, supervising their work and guiding their efforts. Workers must be motivated individually and as groups to utilise their creative efforts in achieving specified objectives. The manager co-ordinates by ensuring that all facilities and individuals sustain and reinforce each other. This requires an efficient system of communication so that each department and section is aware of its role and the assistance to be expected from others. Control involves a constant review of the programme of work in order to check on actual achievements and to rectify if necessary any deviations by applying the necessary corrective measures.

The manager arranges regular site meetings to be attended by all senior supervisory staff and sectional leaders. At such meetings, the quantity surveyor submits a report on the monthly measurements of work executed. The project accountant also submits the site cost sheet with a summary of how much has been spent by each section on plant, labour, materials and other incidental expenses (e.g. petty cash). Under such circumstances, a meaningful discussion of unsatisfactory progress and over-expenditure will be made at the regular site meetings.

The programme of work is one of the manager's most important tools for controlling the progress of work. It must therefore be prepared with great caution. If possible most of the senior section leaders must be involved in its preparation at the very onset. Scheduling is an important stage in the preparation of a working programme. It is a process of fitting the working plan to a time format indicating the start and finish of each activity. At the scheduling stage of a labour-based construction activity, the manager first provides materials that will be needed (including tools if necessary) and then proceeds to assign labour (e.g. labourers, masons, carpenters, steel-benders etc.) needed to complete the activity within an acceptable duration. The use of realistic labour constants is the key to successful management of labour-based methods of construction. Where labour constants are not available, works study, work measurements etc. may be used to provide the required data for a project in a specified location.

**5.3.2 Works Study**

The main purpose of a works study is to discover what time and effort can be saved and made available for other works. Such studies enable existing abilities in an organisation to be matched more carefully with the requirements of specified jobs so that faulty relationships between individuals and work can be rectified. Work measurement, another closely related technique, aims at establishing the time for a qualified worker to carry out a specified job at a defined level of performance. Work measurement helps in comparing times for alternative methods, and allocation of labour to jobs in proportion to the work involved so that an appropriate balance of labour is maintained. The procedure for carrying out work measurement may be outlined as follows:

i. Select and define the work to be studied.

ii. Record all relevant facts of the present method by means of charts diagrams and models.

iii. Examine the facts critically and in sequence.
iv. Develop the most effective method of doing the work.

v. Maintain regular routine checks for the procedure under investigation until it can be established as standard practice.

The Project Planning and Control Division of Ghana's State Construction Corporation (SCC) adopted the works study principles outlined above in establishing labour outputs which have now been approved by the Executives and Workers' Union of the corporation. The labour output document, first produced in 1970 and subsequently amended and approved in 1977, forms the basis for assessing acceptable output from each category of worker. It is also used for establishing taskwork and payment of bonus or incentives.

5.3.3 Labour Constants

The labour constant is a figure which tells how many work-days are spent per unit of work. For example, Appendix A (Table 1) shows that one labourer will excavate 3.82 cubic metres in medium soil per day of eight hours. The labour constant works out to:

\[
1 \text{ work-day} = \frac{0.26 \text{ work-day}}{3.82 \text{ cu. m.}}
\]

If, on the other hand, the excavation had been stony soil one labourer would be expected to excavate only 1.91 cu. metres in the same period and the labour constant would be:

\[
1 \text{ work-day} = \frac{0.52 \text{ work-day}}{1.91 \text{ cu. m.}}
\]

(Please note: The lower the output the higher, the labour constant).

Assume that the base of a culvert or the foundation of a bridge is to be concreted. The following procedure has been found to be effective:

i. Determine the volume of concrete required from the drawings and/or bill of quantities. Check from the specifications of to ascertain the class of concrete. In this case, the recommended mix of proportions by volume is 1:2:4.

ii. Using, table 2 (Appendix A) determine the quantities of materials needed for the concrete works. For example, if 35 cubic metres of concrete (1:2:4 class) will be needed, then 224 bags of cement, 16 cu. metres of fine aggregates (sand) and 32 cubic metres of coarse aggregates will be needed. These quantities may be increased by about 5% to allow for waste.

iii. Provide a good concrete mixer and preferably one that can hold one bag of cement and the aggregates. A stand-by mixer may be arranged.

iv. Prepare gauge boxes, at least one for sand and two for the coarse aggregates. Each gauge box must be designed such that its volume is equal to the volume of one bag of cement. A gauge box of dimensions 300 mm x 300 mm x 390 mm i.e. volume 0.035 cu. metres will be acceptable.

v. The labour force for the concreting operation may consist of:

- one labourer (loading cement)
The labour force for the concreting operation adds up then to 13. Table 3 (Appendix A) shows that the average output for this activity (item 2) is 2.7 cubic metres per worker. The expected output per day is $13 \times 2.7 = 35$ cubic metres. Therefore, the concreting operation can be finished in a day. The concreting operation may then be given out to the selected workers as taskwork (sometimes referred to as "finish and go") i.e. the piece of work is given out to the workers to be completed in a day. The workers are free to go home any time the work is completed. Output can be drastically improved if the concrete mixer and the aggregates are brought as close as possible to the culvert/bridges site. Batching concrete by volume presupposes that the sand is dry. Wet or moist sand can bulk by about 20%. Therefore, if moist sand is used, the volume of sand should be increased by about 20% to allow for bulking. It may be desirable to carry out a sand bulking test to determine the exact value. Quality control measures must be enforced during labour-based concreting operations. Slump tests must be carried out before commencement and during the concreting process to ensure consistency of water/cement ratio. Test cubes must be prepared during the concreting operations. In this example, the gauge box is designed such that the mix proportions by volume are:

- One bag of cement
- Two boxes of sand
- Four boxes of coarse aggregates

The supervisor must ensure that the exact quantities of fine and coarse aggregates are added during each mixing operation. Workers normally easily get carried away by enthusiasm during concrete works under taskwork basis.

### 5.3.4 Arrow Diagram for Highway Construction Project

Major questions that must be answered before an attempt is made to develop a network diagram for the highway construction project are as follows:

1. What are the activities that must be executed in order to complete the project?
2. How is each activity going to be executed?
3. What resources must be allocated to each activity so that it may be completed within an acceptable duration?
4. What is the most acceptable sequence of operations?

The answer to question (1) calls for a complete breakdown of the project into distinct activities. Some of the most popular activities for a highway construction project consist of:

a) Excavation for culverts and bridges.
b) Formwork.
c) Cutting, bending and fixing reinforcement.
d) Concrete works (culverts and bridges).
e) Earthmoving operations.
f) Pavement construction and surfacing.

To answer question (2) one has to examine the availability of local labour and the type of highway design. In the case of the road bridge with cantilever abutments on spread foundations, the excavation, formwork, reinforcement placing, and concrete works may be planned for execution by labour-based methods. Plant-intensive operations in bridge construction may be restricted to piling works, and the launching pre-cast, pre-stressed bridge beams. Earth-moving operations, pavement construction and surfacing may also be executed by plant-intensive methods. Surface dressing, which is very popular with low-cost roads, can be planned for execution by labour-based methods.

Resource allocation is an important phase in the planning strategy. The main resources to be utilised for construction are plant, labour, materials and finance. Plant must be bought or rented for use only when it is absolutely necessary. Indiscriminate use of plant could wipe out the entire profit margin. The same goes for labour. Workers, on recruitment, are the best friends of management. Relations turn sour when the project is about to be completed and lay-offs become imminent. Therefore, if possible, efforts must be made to retain just enough workers to maintain steady progress on the project. Local labour could then be brought in to complete some items of work when the need arises. The sequence of operations must be carefully examined. Although progress can be drastically improved by executing simultaneously as many activities as possible, this strategy must be attempted only when resources are adequate to meet the demand.

### 5.3.5 Analysis of Network Diagram

The network diagram for the highway construction project has been developed and analysed as shown in Fig.1 (Appendix B). The normal procedure for analysing networks has been followed viz.:

i. The Earliest Event Times have been determined by the 'Forward Pass' method while the Latest Event Times have been determined by the 'Backward Pass' method.

ii. Critical activities are those activities whose Earliest Start Times (EST) and Latest Start Times (LST) are the same or the Earliest Finish Times (EFT) and Latest Finish Times (LFT) are the same.
iii. Floats in all the activities have been calculated in Table 1 (Appendix B). Float indicates the range within which the start and finish times of an activity may be delayed without affecting the completion time of the activity.

iv. Eight out of the 15 activities are critical. The project manager must therefore strive to ensure that these critical activities receive utmost attention.

5.3.6 Conclusion

i. Labour-based methods of construction should be encouraged. Therefore, large construction corporations must sponsor studies in these areas.

ii. The use of realistic labour constants, prior consultation with workers, and motivation are some strategies which promote productivity.

iii. It is being argued that labour-based methods suffer from quality deficiencies. Therefore quality measures must be strictly enforced.

Acknowledgements

The author would like to thank the Managing Director of Ghana's State Construction Corporation for granting permission for the use of the Corporation's Labour Output Document.

References


## Appendix A

### Table 1: Labour output: Manual excavation, filling and compaction

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Output 8 hrs/day</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Excavation in soft soil</td>
<td>5.35</td>
<td>C/M</td>
</tr>
<tr>
<td>2</td>
<td>Excavation in sand</td>
<td>9.17</td>
<td>&quot;</td>
</tr>
<tr>
<td>3</td>
<td>Excavation in medium soil</td>
<td>3.82</td>
<td>&quot;</td>
</tr>
<tr>
<td>4</td>
<td>Excavation in hard laterite</td>
<td>2.68</td>
<td>&quot;</td>
</tr>
<tr>
<td>5</td>
<td>Excavation in stony area</td>
<td>1.91</td>
<td>&quot;</td>
</tr>
<tr>
<td>6</td>
<td>Backfilling</td>
<td>8.41</td>
<td>&quot;</td>
</tr>
<tr>
<td>7</td>
<td>Backfilling and compacting</td>
<td>4.20</td>
<td>&quot;</td>
</tr>
<tr>
<td>8</td>
<td>Trimming sides of foundations and trenches</td>
<td>18.28</td>
<td>L.M</td>
</tr>
<tr>
<td>9</td>
<td>Load material and cart away</td>
<td>3.20</td>
<td>&quot;</td>
</tr>
<tr>
<td>10</td>
<td>Hard core filling (200 mm)</td>
<td>5.94</td>
<td>&quot;</td>
</tr>
<tr>
<td>11</td>
<td>Hard core filling (150 mm)</td>
<td>9.14</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

### Table 2: Materials required for one cubic metre of concrete

<table>
<thead>
<tr>
<th>Mix proportions</th>
<th>Cement Weight (kg)</th>
<th>Sand $m^3$</th>
<th>Aggregates $m^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:1:2</td>
<td>530</td>
<td>0.34</td>
<td>0.74</td>
</tr>
<tr>
<td>1:1½:3</td>
<td>410</td>
<td>0.43</td>
<td>0.86</td>
</tr>
<tr>
<td>1:2:4</td>
<td>320</td>
<td>0.45</td>
<td>0.90</td>
</tr>
<tr>
<td>1:2½:5</td>
<td>260</td>
<td>0.46</td>
<td>0.92</td>
</tr>
<tr>
<td>1:3:6</td>
<td>225</td>
<td>0.47</td>
<td>0.94</td>
</tr>
<tr>
<td>1:4:8</td>
<td>170</td>
<td>0.48</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Source: Labour output document of SCC Ghana
### Table 3: Labour output: Concrete works

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Output 8 hrs</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Casting plan in-situ blinding</td>
<td>2.7</td>
<td>m³</td>
</tr>
<tr>
<td>2</td>
<td>Casting concrete in foundation 1 m - 2 m deep</td>
<td>2.7</td>
<td>&quot;</td>
</tr>
<tr>
<td>3</td>
<td>Casting concrete in foundation 2 m - 3 m deep</td>
<td>2.7</td>
<td>&quot;</td>
</tr>
<tr>
<td>4</td>
<td>Casting concrete in beams</td>
<td>2.3</td>
<td>&quot;</td>
</tr>
<tr>
<td>5</td>
<td>Casting concrete in column base</td>
<td>3.8</td>
<td>&quot;</td>
</tr>
<tr>
<td>6</td>
<td>Casting concrete in columns</td>
<td>3.1</td>
<td>&quot;</td>
</tr>
<tr>
<td>7</td>
<td>Casting concrete in ground floor slab</td>
<td>3.4</td>
<td>&quot;</td>
</tr>
<tr>
<td>8</td>
<td>Casting concrete in other floors</td>
<td>2.3</td>
<td>&quot;</td>
</tr>
<tr>
<td>9</td>
<td>Casting concrete in beams at floor level</td>
<td>1.9</td>
<td>&quot;</td>
</tr>
<tr>
<td>10</td>
<td>Casting concrete walls in ground floor</td>
<td>2.3</td>
<td>&quot;</td>
</tr>
<tr>
<td>11</td>
<td>Casting concrete in lintels</td>
<td>3.8</td>
<td>&quot;</td>
</tr>
<tr>
<td>12</td>
<td>Casting concrete in staircase</td>
<td>1.5</td>
<td>&quot;</td>
</tr>
<tr>
<td>13</td>
<td>Casting concrete in roof slab (with hoist)</td>
<td>1.9</td>
<td>&quot;</td>
</tr>
<tr>
<td>14</td>
<td>Casting concrete in roof slab (without hoist)</td>
<td>1.1</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

**Note**
(a) Output is for each worker for 8 hours
(b) Workers for the compacting operation include
1. Workers feeding concrete mixer
2. Concrete mixer operator
3. Dumper operator
4. Other workers laying and compacting concrete.

Source: Labour output document of SCC, Ghana
### Appendix B

**Analysis of network diagram: Highway Construction Project**

#### Table 1

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration (days)</th>
<th>Early Start (EST)</th>
<th>Finish (EFT)</th>
<th>Latest Start (LST)</th>
<th>Finish (LFT)</th>
<th>Total Float</th>
<th>Free Float</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 2</td>
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<td>14</td>
<td>0</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>Critical</td>
</tr>
<tr>
<td>2 - 3</td>
<td>9</td>
<td>14</td>
<td>23</td>
<td>14</td>
<td>23</td>
<td>0</td>
<td>0</td>
<td>Critical</td>
</tr>
<tr>
<td>3 - 5</td>
<td>13</td>
<td>23</td>
<td>36</td>
<td>23</td>
<td>36</td>
<td>0</td>
<td>0</td>
<td>Critical</td>
</tr>
<tr>
<td>5 - 8</td>
<td>29</td>
<td>36</td>
<td>65</td>
<td>36</td>
<td>65</td>
<td>0</td>
<td>0</td>
<td>Critical</td>
</tr>
<tr>
<td>8 - 11</td>
<td>14</td>
<td>65</td>
<td>79</td>
<td>65</td>
<td>79</td>
<td>0</td>
<td>0</td>
<td>Critical</td>
</tr>
<tr>
<td>11 - 12</td>
<td>14</td>
<td>79</td>
<td>93</td>
<td>79</td>
<td>93</td>
<td>0</td>
<td>0</td>
<td>Critical</td>
</tr>
<tr>
<td>12 - 13</td>
<td>15</td>
<td>93</td>
<td>108</td>
<td>93</td>
<td>108</td>
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<td>0</td>
<td>Critical</td>
</tr>
<tr>
<td>13 - 14</td>
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<td>108</td>
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<td>108</td>
<td>122</td>
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<td>0</td>
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<tr>
<td>2 - 4</td>
<td>8</td>
<td>14</td>
<td>22</td>
<td>28</td>
<td>36</td>
<td>14</td>
<td>14</td>
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</tr>
<tr>
<td>3 - 7</td>
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<td>23</td>
<td>36</td>
<td>62</td>
<td>67</td>
<td>39</td>
<td>39</td>
<td>Non-Critical</td>
</tr>
<tr>
<td>7 - 9</td>
<td>5</td>
<td>36</td>
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<td>67</td>
<td>72</td>
<td>31</td>
<td>0</td>
<td>Non-Critical</td>
</tr>
<tr>
<td>9 - 11</td>
<td>7</td>
<td>41</td>
<td>79</td>
<td>72</td>
<td>79</td>
<td>31</td>
<td>0</td>
<td>Non-Critical</td>
</tr>
<tr>
<td>3 - 6</td>
<td>50</td>
<td>23</td>
<td>73</td>
<td>24</td>
<td>74</td>
<td>1</td>
<td>1</td>
<td>Non-Critical</td>
</tr>
<tr>
<td>6 - 10</td>
<td>14</td>
<td>73</td>
<td>87</td>
<td>74</td>
<td>88</td>
<td>1</td>
<td>0</td>
<td>Non-Critical</td>
</tr>
<tr>
<td>10 - 13</td>
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<td>108</td>
<td>88</td>
<td>108</td>
<td>1</td>
<td>0</td>
<td>Non-Critical</td>
</tr>
</tbody>
</table>

**Notes:**

1. EST = Earliest Start Time; LST = Latest Start Time
2. EFT = Earliest Finish Time; LFT = Latest Finish Time
3. Total float is the maximum time an activity can be delayed without affecting the completion time of the project.
4. Free float is the excess of available time over the activity duration assuming that the activity under consideration and all succeeding activities start at the earliest possible time.