Increased Application of Labour-Based Methods *through* Appropriate Engineering Standards

Regional Report

TRL

DFID Department for International Development

ILO

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Abbreviations

ADT	–	Average daily traffic
CBR	–	California Bearing Ratio
DFID	–	Department for International Development
GL	–	Gravel Loss
GM	–	Grading Modulus
HDM	–	Highway Design Model
ILO	–	International Labour Organization
ILO/ASIST	–	International Labour Organization/Advisory Support, Information Services and Training
IRI	–	International Roughness Index
PP	–	Plasticity Product
TMI	–	Thornthwaite's Moisture Index
TRL	–	Transport Research Laboratory, UK
vpd	–	vehicles per day

Executive Summary

Road access to health centres, schools, jobs, etc. is an important factor in the social and economic development of rural communities in Africa. Most roads providing access to small towns and villages tend to be unsealed and constructed of earth or gravel. Climatic and environmental influences can be dominant factors in the deterioration of these roads and their life-time performance is also influenced by factors such as terrain and construction materials, as well as traffic. Access, through reduced trafficability and passability, is often severely curtailed in the wet season. With unpaved roads typically comprising 70-80% of road networks in Africa, the investment in these roads represent a considerable proportion of the asset value of the total road network.

At the Extraordinary African Heads of States meeting held in October 2004 in Ouagadougou, Burkina Faso, to discuss employment and poverty reduction issues, the heads of states made a commitment to use employment-friendly approaches in all sectors that have employment creation potential. Infrastructure, especially the road sectors is one that has a high potential for creating employment provided the appropriate choice of technology is made.

The roads are seldom designed, let alone properly appraised. Where appraisals have been carried out, the costing usually only covers the planning and construction stages. This information is normally obtained from the Bill of Quantities, which in some cases is not produced. Many roads are constructed by labour-based technology, which can further restrict haulage and access to good road building materials, more-so in subsequent regravelling activities. The consequences in qualitative terms, from the use of inferior materials such as ravelling and/or slipperiness, are well known and current specifications cover these aspects adequately. However, their performance in terms of gravel loss and roughness progression, which determine their very sustenance and the resultant life-cycle costs, are less known. In addition, the existing standards and specifications are based on structural requirements rather than performance. This has had a huge impact on the sustainability of rural and peri-urban roads. It is interesting to see how in some cases roads that mushroom through some well-intended programmes quickly disappear not long after they are completed. The inadequate budgets for the management of road networks have left responsible agents strapped for funds for the maintenance of existing roads, let alone sustenance for developing new roads. Some regions are posting a net loss in rural road infrastructure as a result.

The goal of this project was 'To promote sustainable livelihoods and contribute to the socio-economic development of disadvantaged rural populations through the provision of improved road access'. The purpose was 'To reduce the life-time costs of unpaved rural roads by promoting appropriate engineering standards, planning tools and works procedures for labour-based construction and maintenance'. The factors influencing deterioration of unpaved roads and their effect on the overall performance of the roads have been determined in this project. To achieve this, test sites were selected and established in Ghana, Uganda and Zimbabwe and parameters such as material properties, traffic, environment, etc. were studied over a 2-year period. A detailed analysis was carried out and the results were interpreted into useable information in the form of new performance-based standards and specifications and a useful life-cycle costing software tool. This has resulted in increased opportunities for better and more robust engineering designs for rural unpaved roads. The life-cycle costing tool will be useful to decision-makers, planners, roads authorities, and donors alike, as it can be used as an investment tool. Appropriate decisions can be made and justified from the outset that will ultimately culminate in sustainable rural road networks.

Improved access significantly contributes to the well-being of communities living in the area. It is for this reason that there is an increased demand for access roads. As the demand for access is high, it is essential to increase the use of locally available resources and cost-efficient methods of delivery. Low volume trafficked roads are suitable for the use of appropriate technology that promotes local resources. This approach will speed up local economic development and intensify the fight against poverty. It is for these reasons most national development plans have included employment as central to the improvement and maintenance of infrastructure.

Appropriate standards and specifications alone are not enough to guarantee good performance of roads. Much also hinges on the quality standards employed in the approval of materials and works. This issue has been addressed in this project through the development of a quality assurance Guideline entitled 'Guideline for Quality Assurance Procedures and Specifications for Road Works Executed using Labour-Based Methods'. The Guideline will assist in quality control and workmanship on labour-based projects. This in turn will ensure value for money for clients and rapid approval of works carried out by contractors. Above all, this will lead to the production of good quality products, the impact of which will be an increase in the application of the labour-based technology.

The objectives of the project have been largely met. The deterioration relationships and the associate life-cycle costs tool that have been developed, the review of engineering standards and specifications and the quality assurance guideline will all assist in promoting labour-based technology to a new level where it can be viewed as a more competitive option. The provision of good quality roads using labour-based methods through the use of appropriate standards and specifications and tools will contribute to sustained rural and peri-urban development, thereby impacting positively on poverty. This will fulfil the goal of this project.

Notwithstanding the positive results of this project, the full benefits will not be realised unless these research findings and output are implemented to enhance best practice in the application of labour-based methods. It is therefore recommended that a comprehensive programme for awareness, dissemination, training, trialling and mainstreaming be formulated and executed. This will result in the efficient use of resources currently earmarked for labour-based works in various countries in Africa and beyond.

1. Introduction

1.1 Background

Low-volume earth and gravel roads are often constructed by labour-based methods using quite different construction techniques and lighter equipment than used on projects constructed by conventional methods. Quantitative information on the engineering performance and modes of deterioration of these types of road is limited and thus it is difficult to set appropriate standards or to know the effect of different standards on their performance. This means that the expected level of maintenance is difficult to ascertain, and whole-life costs and benefits are almost impossible to determine.

In addition, most road authorities and agencies have noted concerns over the huge burden associated with sustaining rural unpaved roads in general. Whilst some roads may last a long time, others have very short re-gravelling cycles (2 to 3 years). Under such circumstances the cost of sustaining such networks exceeds the capacity of responsible authorities, resulting in the poor state of roads. With increased awareness, road users are demanding better services in line with levies that they pay for road provision and as such, good riding quality and low vehicle operating costs are now an issue. To improve the condition of roads, many authorities have adopted performance-based maintenance techniques in which the quality of road determines the work that needs to be done to maintain the desirable standards.

It is therefore imperative that factors influencing deterioration and maintenance demands are considered and investigated in order that mitigating measures are put in place through engineering processes and standards. To achieve this objective, currents standards and specifications, which are more inclined towards structural strength, needed reviewing in order to develop new standards that are based on both performance and structural strength. It is also acknowledged that performance is mainly dependent on the quality of materials used, the workmanship, the appropriateness of the piece of infra-structure to its intended functionality and the influencing environment. A measure of performance is paramount to the whole process, and in the case of unpaved roads the performance is commonly measured by the rate of gravel loss and rate of roughness progression.

Therefore, quantitative information on the modes of deterioration is required for different types of very low-volume roads so that appropriate engineering standards can be set, methods to monitor compliance with standards developed and procedures determined that enable life-cycle costs to be calculated.

The importance of well-defined standards has become particularly evident, with the current emphasis on private sector involvement in low-volume road projects through the training and engagement of small-scale contractors. Construction of roads, whether highly trafficked trunk roads or village tracks, by the private sector is conducted as a business and, as with any business, reducing costs increases profits. Whilst measures that reduce costs through increased efficiency are to be encouraged, those which result in poor quality are not acceptable. Without setting appropriate standards and methods to monitor compliance with these standards, it is impossible to check on the quality of roads being constructed.

Labour-based methods and other less conventional techniques are used to construct a wide variety of roads, which vary from tracks providing basic access to highly trafficked gravel roads and, occasionally, even sealed roads. On lightly trafficked roads, construction standards will to some extent depend on the equipment available. Deterioration due to environmental and climatic effects on these roads can be greater than that due to traffic. This is the important difference between these and more highly trafficked roads.

The outcome of this project is expected to culminate in a number of benefits for road agencies and authorities, the peri-urban and rural communities:

1. Use of appropriate standards and specifications will result in more sustainable and manageable road networks, thus reducing the maintenance burden and increasing the opportunities for the expansion of road networks and improved accessibility.
2. The use of performance based designs will enhance durability of the roads, thereby reducing the demand for gravel extraction and environmental degradation.
3. More appropriate decisions will be made at planning and design stages in order to ensure quality and performance. This will help to reduce the maintenance burden, which is a major issue for authorities and agencies responsible for low-volume roads as funding is almost always limited.
4. The information emanating from the research is in itself an important tool for the decision-makers in determining appropriate road types for different environments.
5. The life-cycle costing methodology will also be a useful tool, adding a new dimension incorporating economic considerations as an integral part of low-volume roads provision. This will be a useful negotiating tool not only for project appraisal but for soliciting funding from donors and other financiers.
6. Communities, especially the marginalised populace, will benefit immensely from improved transport services resulting from increased sustainability of low-volume road networks.
7. Perhaps the highest beneficiary will be labour-based technology itself. Improved standards and quality will result in greater appreciation of labour-based technology and this is likely to improve its competitiveness, acceptability and reliability.

1.2 Project objectives

The project goal is to promote sustainable livelihoods and contribute to the socio-economic development of disadvantaged rural populations through the provision of improved road access.

The purpose of the project is to reduce the life-time costs of unpaved rural roads by promoting appropriate engineering standards, planning tools and works procedures for labour-based construction and maintenance.

This project has been carried out in partnership with the International Labour Organisation/Advisory Support, Information Services and Training (ILO/ASIST).

1.3 Outputs

The main outputs of the project are:

a) Deterioration relationships established for low-volume unpaved roads.
b) Methodologies developed and documented for determining life-cycle costs of labour-based roads.
c) Appropriate engineering standards developed and guidelines produced for different categories of labour-based roads in different environments.

d) Appropriate methods established and guidelines produced for quality approval of labour-based construction and maintenance works.
e) Results disseminated to training institutions, relevant ministries and small-scale contractors associations.

The outputs of the project will contribute to increasing awareness by road authorities and other stakeholders, such as policy- and decision-makers, communities, professional bodies, etc. of the potential benefits of using optimised labour-based road technology and increase the applicability of local resource use.

1.4 Reports

Three studies investigating the performance and standards of roads that are constructed by labour-based methods were carried out in Ghana, Uganda and Zimbabwe. Individual country reports were produced with recommendations and guidance based on that country only. This report synthesises the findings from the three countries and provides guidelines for countries with similar terrain, climate and materials.

The report has been produced to give a regional perspective to the findings for applications by a wider spectrum of practitioners in different countries. It should be noted though that the programme of work is expanding as more countries continue to join in and participate in the research. The results and outcomes will continue to be improved as more information becomes available from on-going projects and others that have yet to start. Technically and statistically, results and outcomes of research become more reliable with increased amounts of data. It should be noted, however, that the results of this research have produced very useful tools which are documented in this and other reports.

In addition to this report, a manual entitled 'Guideline for Quality Assurance Procedures and Specifications for Road Works Executed Using Labour-Based Methods' has been produced covering

1. Standards and specifications for the selection of materials.
2. Standards and specifications for the approval of works.
3. Quality assurance through planning and design.
4. Economic appraisal through the life-cycle costing tool (software programme).

The guideline is a useful document for labour-based practitioners and also non-labour-based practitioners, providing the means to ensure that good quality roads are built, thereby enhancing value for money for the clients. In addition, the quality of labour-based works has been a contentious issue, creating a barrier to the development and promotion of the technology. This guideline will help to promote the use of labour-based technology and this will in turn help fulfil one of the major objectives of this project which is the '*increased application of labour-based techniques and whole-life costing for low volume labour-based and unpaved roads*'.

2. Scope of Study

2.1 Test site selection process

The objective of the test site selection process was to select lengths of road that had been constructed using labour-based techniques that covered a wide spectrum of factors, primarily traffic, construction materials and climate. The site selection approach adapted in this study is shown in Figure 2.1.

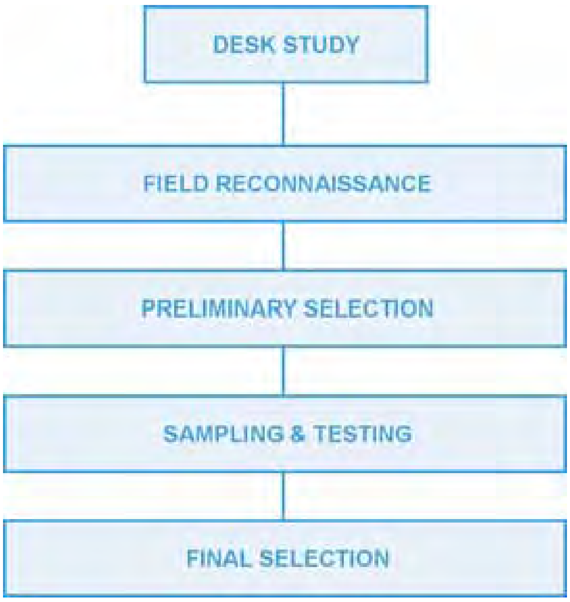
Desk study

At this stage available information, data and local experiences were collected and coordinated. This process helps to map a picture of the local situation and develop a strategy for implementation of the project. The desk study was carried out on the basis of a research matrix which encompassed material properties, traffic, terrain, road geometry, climate and construction (age and standards). The range for each of these parameters in any one country is usually limited, hence the project took a regional perspective to cover wider ranges. Possible candidate roads were considered at this stage, focusing on the need to cover as much of the elements of the matrix as possible.

Field reconnaissance

Once the desk study was completed and possible locations of sites identified, the authorities responsible for these roads were requested to select candidate roads with specific emphasis on the particular aspects

Figure 2.1
Test site selection process



of the matrix as depicted by the desk study. This process also identified potential duplicate locations. Field visit were made to the selected roads and this marked the beginning of site selection.

Preliminary site selection

Preliminary site selection was carried out based on the research matrix, primarily traffic levels, road alignment, climate and the gravel wearing course material. Material properties constitute the most important part of the research and visual assessments alone are not adequate. For this reason samples were collected for testing.

Sampling

Samples of wearing course were collected from each site. Usually, one sample was collected from the centre of the carriageway. In some cases two samples were collected and results would then be averaged. Care was taken to avoid contamination of the wearing course and the underlying subgrade. Also it was necessary to ensure that the sample was big enough to carry out sieve analysis and determine Atterburg limits for plasticity. In some cases proctor tests and CBR were taken into consideration. During sampling the depth of wearing course was measured – this was also a useful parameter for selection. Sites with less than a 50mm wearing course thickness were rejected as this was not enough to last through the monitoring period.

Final selection

All the data were collated and analysed, and the results were used to produce a final list of sites for the project.

Thornthwaite's Moisture Index (TMI) was considered a suitable measure to indicate climate in a region. Climatic boundaries in terms of TMI encountered in the three countries have been classified as shown in Table 2.1.

Table 2.1: Climate classification based on TMI contours

TMI Range	Climate Classification
+20 to 0	Moist sub-humid
0 to -20	Dry sub-humid
-20 to -40	Semi-arid

Terrain in which the test sites were situated was classified as either flat, rolling or mountainous, as described in Table 2.2.

Table 2.2: Terrain classes

Class	Description
Flat	0 – 10 five metre ground contours per km
Rolling	11 – 25 five metre ground contours per km
Mountainous	> 25 five metre ground contours per km

Soil samples were collected from these roads to determine their classification, plasticity and grading. The results of these tests were used to eliminate duplication of similar roads as possible locations for the test sites.

2.2 Selected test sites

A total of 63 test sites were selected in the three countries, 24 sites in Ghana, 8 sites in Uganda and 31 sites in Zimbabwe, as shown in Table 2.3, Table 2.4 and Table 2.5 respectively. For easy referencing, the sites were referred to by a code consisting of four letters, the first and last letter of the two places connected by the road. For example the test site on the **N**ah**A**-**L**ogg**U** road was referred to as NALU.

Table 2.3: Ghana test sites

No.	Road Name	Site Code	Climate	Material
1	Assin Ayaasi – Assin Kruwa	AIAA	Moist sub-humid	Fine lateritic gravel
2	Abrewanko J'tn – Abrewanko	ANAO	Dry sub-humid to semi-arid	Lateritic gravel
3	Ayomso – Awia Awia	AOAA	Dry sub-humid	Brown lateritic gravel
4	Asuotiano – Dorma Akwamu	AODU	Dry sub-humid	Stoney gravel
5	Asawinso – Kojokrom	AOKM	Moist sub-humid	Fine lateritic gravel
6	Bulenga – Chaggu	BACU	Semi-arid	Fine lateritic gravel
7	Bonakye – Potimbo	BEPO	Semi-arid	
8	Bechem – Bremie	BMBE	Dry sub-humid	Brown coarse laterite
9	Bonzain J'tn – Bonzain	BNBN	Moist sub-humid	Fine lateritic gravel
10	Bodi J'tn – Nsawura	BNNA	Humid	Coarse lateritic gravel
11	Dimala – Bongnayili	DABI	Semi-arid	
12	Duayaw Nkwanta – Camposo	DACO	Dry sub-humid	Brown lateritic gravel
13	Dominanse – Wrakese S'tn	DEWN	Moist sub-humid	Fine lateritic gravel
14	Datano – Kokooso	DOKO	Moist sub-humid	Fine lateritic gravel
15	Forifori – Dwamena	FIDA	Semi-arid	
16	Grumani J'tn – Kpachiyili	GNKI	Semi-arid	
17	Linso – Nframakrom	LONM	Sub-humid	Sandy gravel
18	Naha – Loggu	NALU	Semi-arid	Lateritic gravel
19	Nabogu – Sung	NUSG	Semi-arid	
20	Pong Tamale – Yapalsi	PEYI	Semi-arid	
21	Samanhyia – Kyemfre	SAKE	Dry sub-humid to semi-arid	
22	Wiaga – Kpalansa	WAKA	Semi-arid	Lateritic gravel
23	Wamfie – Praprababida	WEPA	Dry sub-humid	Brown laterite gravel
24	Zebilla – Timunde	ZATE	Semi-arid	Lateritic gravel

Table 2.4: Uganda test sites

No.	Road Name	Site Code	Climate	Material
1	Kisanja – Paraa	KAPA	Semi-arid	Brown clayey gravel
2	Kisoro – Muganza	KOMA	Wet humid to sub-tropical	Dark brown sandy clay
3	Muhokya – Mahango	MAMO	Wet humid to sub-tropical	Dark grey volcanic ash
4	Mparo – Kibugubya	MOKA	Semi-arid	Dark grey clayey soil
5	Molo – Kidoko	MOKO	Wet humid to sub-tropical	Brown quarzitic gravel
6	Nakaloke – Kabwangasi	NEKI	Wet humid to sub-tropical	Black cotton soil
7	Nankusi – Bumudu	NIBU	Wet humid to sub-tropical	Dark red clayey gravel
8	Rubona – Kabuzige	RAKE	Wet humid to sub-tropical	Brown sandy clayey gravel

Table 2.5: Zimbabwe test sites

Road Name	No.	Site Code	Climate	Material
Chikuku – Makuwaza	1 2	CUMA 1 CUMA 2	Dry sub-humid Dry sub-humid	Quartz Quartz
Katarira – Mahuwe	3 4 5	KAME 1 KAME 2 KAME 3	Dry sub-humid Dry sub-humid Dry sub-humid	Sandstone Sandstone Sandstone
Maranda – Mwenezi	6 7	MAMI 1 MAMI 2	Semi-arid Semi-arid	Calcrete Calcrete
Mkwasine – Matsange	8 9 10	MEME 1 MEME 2 MEME 3	Semi-arid Semi-arid Semi-arid	Laterite Laterite Laterite
Mutoko – Nyamuzuwe	11 12	MONE 1 MONE 2	Dry sub-humid Dry sub-humid	Quartz Quartz
Mpoengs – Maphisa	13 14	MSMA 1 MSMA 2	Semi-arid Semi-arid	Calcrete Calcrete
Nyamaropa – Chiso	15 16	NACO 1 NACO 2	Dry sub-humid Dry sub-humid	Quartz Quartz
Nyanga – Rwenya	17 18	NARA 1 NARA 2	Dry sub-humid Dry sub-humid	Quartz Quartz
Nyafaru – Katiyo	19 20	NUKO 1 NUKO 2	Moist sub-humid Moist sub-humid	Quartz + Feldspar Quartz + Feldspar
Plumtree – Somnene	21 22	PESE 1 PESE 2	Dry sub-humid Dry sub-humid	Quartz Quartz
Suswe – Chitsungo	23 24	SECO 1 SECO 2	Dry sub-humid Dry sub-humid	Iron oxide, Quartz Iron oxide, Quartz
Sarahuru – Maranda	25 26	SUMA 1 SUMA 2	Dry sub-humid Dry sub-humid	Feldspar Feldspar
Tinde – Pashu	27 28 29	TEPU 1 TEPU 2 TEPU 3	Dry sub-humid Dry sub-humid Dry sub-humid	Quartz + D. Granite Quartz Quartz + D. Granite
Tsholotsho – Sihazela	30 31	TOSA 1 TOSA 2	Dry sub-humid Dry sub-humid	Calcrete Calcrete

The terrain in which the test sites were located, together with the climate, are shown in Table 2.6.

Table 2.6: Terrain and climate of test site locations

Terrain	Climate					
	Semi-arid		Dry Sub-humid		Moist Sub-humid	
Flat	Ghana	BACU	Ghana	BMBE	Ghana	LONM
		BEPO		WEPA		
		DABI			Zimbabwe	NUKO 1
		FIDA	Zimbabwe	KAME 2		NUKO 2
		GNKI		KAME 3		
		NALU		NARA 2	Uganda	NEKI
		NUSG		PESE 1		
		PEYI		PESE 2		
		WAKA		SUMA 1		
		ZATE		SUMA 2		
				TEPU 1		
	Zimbabwe	MAMI 1		TEPU 2		
		MAMI 2		TEPU 3		
		MEME 1		TOSA 1		
		MEME 2		TOSA 2		
		MEME 3				
		MSMA 1				
		MSMA 2				
	Uganda	KAPA				
Rolling	Uganda	MOKA	Ghana	ANOA	Ghana	AIAA
				AOAA		AOKM
				AODU		BNBN
				DACO		BNNA
				SAKE		DEWN
						DOKO
			Zimbabwe	CUMA 1	Uganda	KOMA
				CUMA 2		MOKO
				KAME 1		
				NACO 1		
				NACO 2		
				NARA 1		
				SECO 1		
Mountainous			Zimbabwe	MONE 1	Uganda	MAMO
				MONE 2		NIBU
				SECO 2		RAKE

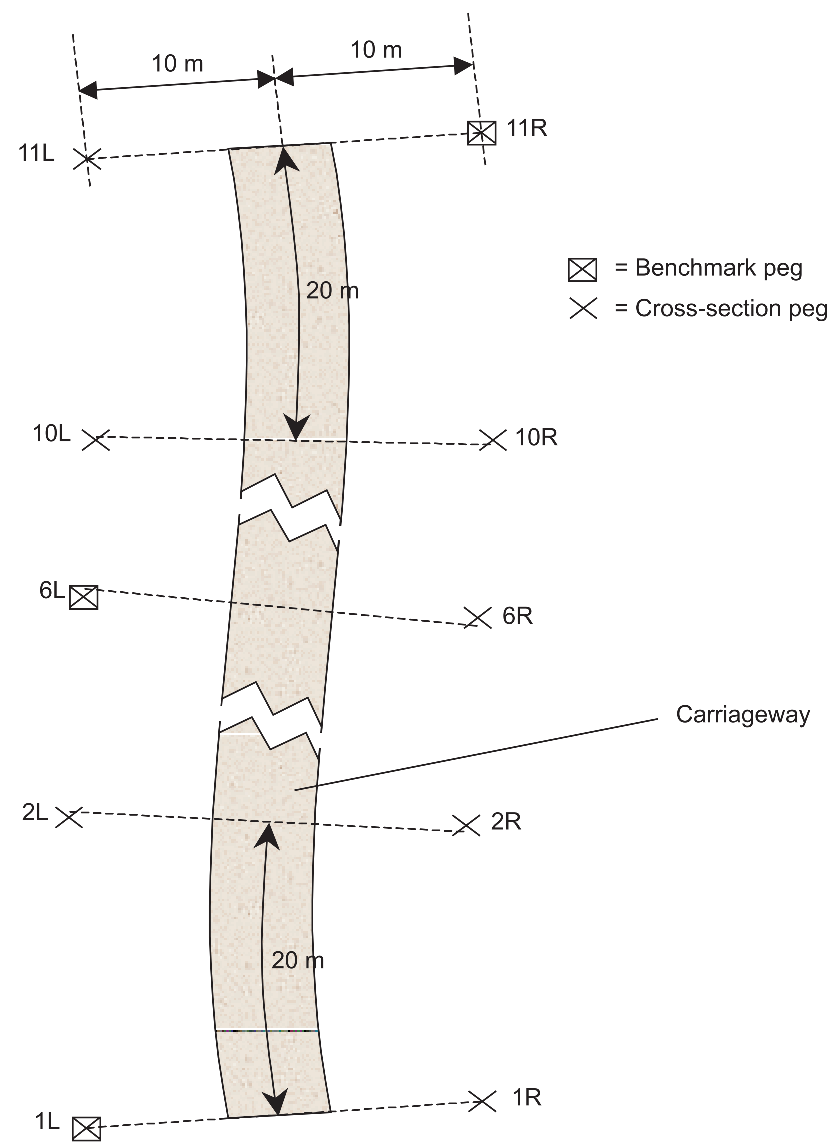
2.3 Site commissioning

The sites were commissioned by establishing steel pegs at 20 m intervals on both sides of the road over the 200 m length of the site. These steel pegs were then used as fixed references for measuring gravel loss. Figure 2.2 shows the typical layout of the pegs.

After concreting the pegs, they were surveyed with an automatic level and staff to establish their relative positions or reduced levels in relation to the benchmarks. The survey was closed back in order to ensure that the required accuracy was achieved. A tolerance of 6 mm was allowable for this survey, referred to as the peg survey. Reduced levels were calculated and recorded.

Surveys of the change in the road profile were taken between the benchmarks. This was carried out by pulling a measuring tape across to road between two pegs at each cross-section and taking levels at 20 cm intervals.

Figure 2.2
Plan view of peg layout on site



3. Test Site Details

3.1 Traffic

Classified traffic count surveys were carried out on the test sites. The ranges of traffic levels (Average Daily Traffic – ADT) observed on the sites in each country are shown in Table 3.1. Also shown in Table 3.1 are the average compositions of light vehicles (< 3.5 tonnes) to heavy vehicles (> 3.5 tonnes) observed on these sites in each country.

Table 3.1: Traffic levels

Country	Average Daily Traffic (ADT)			% Light Vehicles	% Heavy Vehicles
	Min	Max	Average	ADL	ADH
Ghana	3	462	127	62%	38%
Uganda	4	226	58	82%	18%
Zimbabwe	4	140	38	74%	26%

3.2 Rainfall

Data from the rainfall stations located nearest each test site were collected from the country's meteorological office and assigned as the rainfall for that site. The ranges of annual rainfall recorded for the sites in each country are shown in Table 3.2.

Table 3.2: Range of annual rainfall

Country	Rainfall (mm/year)		
	Min	Max	Average
Ghana	539	1485	1135
Uganda	462	2231	913
Zimbabwe	731	1415	1010

3.3 Road alignment

The gradient of each site was measured using a rod and level. The ranges of the vertical alignment on the sites in each country are shown in Table 3.3.

Table 3.3: Range of test site gradients

Country	Gradient (m/km)		
	Min	Max	Average
Ghana	1.0	23.7	11.6
Uganda	11.9	47.8	27.3
Zimbabwe	0.9	67.1	17.9

3.4 Material properties

Samples of the gravel wearing course and the subgrade were taken for material testing from the centre of the carriageway at locations that were immediately adjacent to each of the 200 m test sites. Tests carried out on the samples included grading analysis, Atterberg and shrinkage limits. The results of the tests on the gravel wearing course are summarised in Table 3.4 and on the subgrade material are summarised in Table 3.5.

The grading envelopes from the samples of the gravel wearing course from the three countries are illustrated in Figure 3.1 and for the samples of the subgrade are illustrated in Figure 3.2.

Table 3.4: Material properties of the gravel wearing course

Material Property		Ghana		Uganda		Zimbabwe	
		Range	Average	Range	Average	Range	Average
Liquid Limit	W_L	21 - 48	32.0	29 - 55	45.1	19 - 47	30.0
Plastic Limit	P_L	12 - 26	17.9	0 - 30	18.8	13 – 30	18.2
Plasticity Index	I_p	4 - 22	13.9	17 - 44	26.4	0 - 27	8.0
Plasticity Modulus	PM	136 - 1001	498	352 - 1431	786	0 - 1134	331
Plasticity Product	PP	77 - 740	310	44 - 1032	551	0 - 756	211
Plasticity Factor	PF	197 - 751	386	0 - 1075	479	0 - 1032	311
Dust Ratio	DR	0.31 - 0.90	0.59	0.13 - 0.87	0.63	0.22 - 0.69	0.50
Coarseness Index	I_c	12 – 71	48	33 - 75	51	1 - 59	32
Grading Modulus	GM	1.2 - 2.3	1.9	1.4 - 2.4	2.0	1.0 - 2.2	1.7
Grading Coefficient	Gc	6.0 - 20.6	15.5	3.1 - 20.5	14.5	0.4 - 17.5	10.0

Table 3.5: Material properties of the subgrade

Material Property		Ghana		Uganda		Zimbabwe	
		Range	Average	Range	Average	Range	Average
Liquid Limit	W_L	18 – 55	27.4	40 – 84	50.3	16 - 48	27.7
Plastic Limit	P_L	8 – 32	15.1	19 - 51	26.6	13 - 29	18.5
Plasticity Index	I_p	5 – 23	12.3	16 - 33	23.6	0 - 20	5.0
Plasticity Modulus	PM	218 – 1544	696	320 - 2508	1626	0 - 1590	330
Plasticity Product	PP	117 – 1136	435	160 - 2376	1232	0 - 1200	190
Plasticity Factor	PF	154 – 1615	536	290 - 3672	1403	0 - 1680	304
Dust Ratio	DR	0.27 – 0.82	0.59	0.50 – 0.95	0.72	0.21 – 0.75	0.47
Coarseness Index	I_c	3 - 55	26.1	0 - 55	18.8	0 - 59	17.3
Grading Modulus	GM	0.5 - 2.1	1.4	0.3 - 2.3	1.0	0.6 - 2.0	1.3
Grading Coefficient	Gc	2.3 - 19.6	12.2	0 - 12.5	8.4	0 – 17.3	8.0

Figure 3.1
Grading envelope for the gravel wearing course

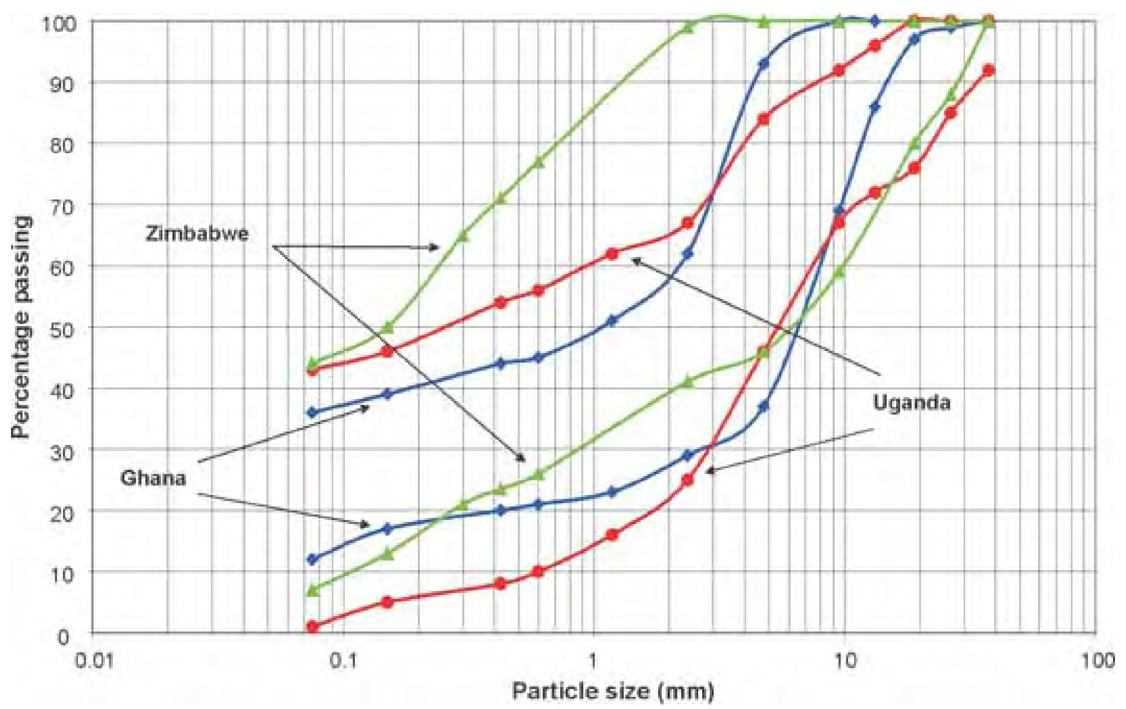
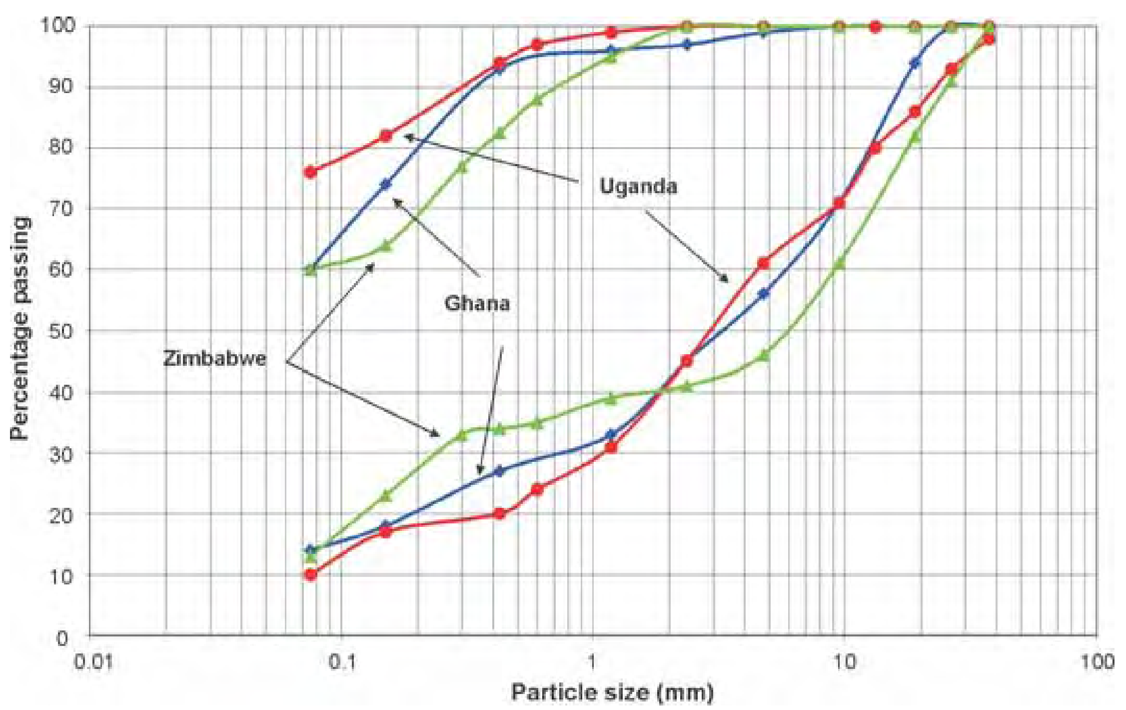


Figure 3.2
Grading envelopes for the subgrade



4. Monitoring

The test sites were regularly monitored for a period of approximately 2 years. In Ghana the monitoring commenced in March 2002, in Uganda in May 2002 and in Zimbabwe in October 2001. The sites in Ghana were monitored a total of four times, in Uganda seven times and in Zimbabwe three times.

The following surveys were conducted during each monitoring site visit:

a. Gravel loss measurements.
b. Roughness measurements.
c. Visual condition survey.

Most of the survey work was carried out by local teams as part of their contribution to their respective project. In addition, the use of local personnel fitted well with one of the main principles of the project of transferring knowledge and research technology to local practitioners through practical involvement. Initially, the team members were trained on how to conduct the surveys. In most cases, levelling was carried out by trained surveyors and materials testing by qualified materials technicians. Mentorship was provided until adequate hands-on experience was attained. Field forms were produced by TRL and the same forms were used in all the participating countries.

Visual condition surveys proved to be more difficult because of the subjective nature associated with the assessment being done by different individuals in different countries with different perspectives. The guide that was provided on the parameters and methodology of assessment helped the reduce subjectivity but did not eliminate it.

4.1 Gravel loss

Gravel loss was estimated by monitoring cross-section profiles of the road between each pair of pegs, i.e. every 20 m along the test site. At each cross-section, the spot height was measured at 20 cm intervals (called offsets) across the carriageway using a rod and level. The 20 cm intervals were identified using a measuring tape held tightly across the carriageway between a pair of pegs. The spot heights were then referenced to the benchmark readings.

Before measuring the cross-section profiles, it was important to check whether the pegs had moved, as movement of the pegs would significantly affect the profile and the estimated gravel thickness/loss. The height of each peg was therefore checked against the original survey records at the start of each survey and any movement taken into account when comparing the reduced levels between surveys.

The width of the carriageway was determined at each cross-section on a test site and the average of the reduced levels across the defined width was used to estimate the height of the gravel wearing-course at each cross-section. The same defined width at a cross-section was used throughout the monitoring period. The change in the average height of the carriageway between surveys was used as the indicator of the change in gravel loss.

4.2 Roughness

Roughness is a measure of the riding quality of the surface and can be measured using a variety of instruments. Whichever instrument is used, it is important that the measurements are standardised in the universally accepted units of International Roughness Index (IRI). A relatively inexpensive roughness measuring device is the Merlin (see Figure 4.1) and it was used to measure roughness on the test sites. The measurements from the Merlin can be standardised to IRI units. The Merlin's operation is detailed in the Test Site Selection, Commissioning and Monitoring report.

The Merlin can be operated in one of two different modes based on the location of the measuring foot shown in Figure 4.2. By changing the position of the foot the magnification factor can be set to either 5:1 (for rough surfaces) or 10:1 (for smooth surfaces), indicating how far the chart pointer moves compared to the measurement probe. For the unsealed labour-based sites, a magnification of 5:1 was used. Prior to use, the Merlin has to be calibrated to correct any discrepancy in the magnification between the probe and the chart pointer.

The number of Merlin measurements along the site (in each wheelpath) should be approximately 200 to ensure that the data are representative of the site. The measurement interval is usually determined by the circumference of the Merlin wheel, i.e. the distance along the ground travelled by one rotation of the wheel, which is approximately 2.1 m. Hence for the 200 m long test sites, it was necessary for a reading to be made every half revolution of the Merlin wheel, which meant that approximately 190 readings were made in each wheelpath.

Figure 4.1
MERLIN roughness measuring device

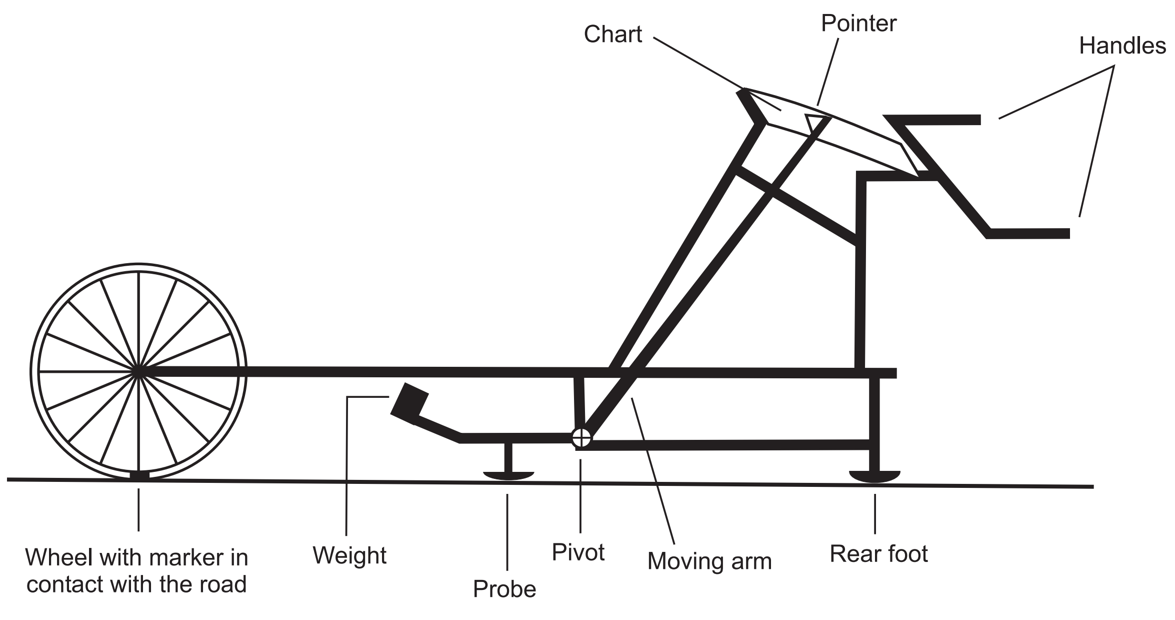
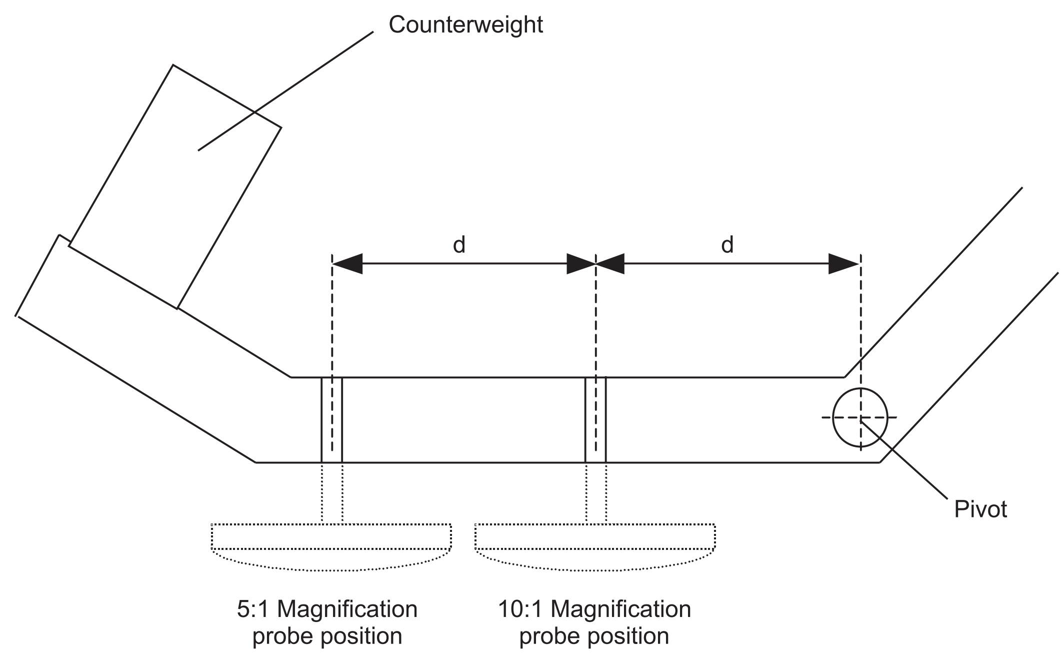


Figure 4.2
Merlin probe assembly



The measure of spread of 90% of the Merlin readings (i.e. 5% of readings from either end of the distribution are ignored) is referred to as 'D'. The roughness, in terms of IRI units, was then evaluated using the relationship:

$$IRI = 0.593 + (0.0471 \times D)$$

4.3 Visual condition survey

Each 200 m test site was divided into 20 m sub-sections with the pegs forming the boundaries. For each 20 m sub-section, the surface condition was recorded on a data sheet, as shown in Appendix B, by a surveyor/technician who walked along the road. The parameters that were recorded are listed in Table 4.1, with the drain and shoulder information collected separately for both the left and right side of the road.

Table 4.1: Visual condition codes

	Parameter	Ranges
Drain	Drainage	Very Good, Good, Average, Poor, Very Poor
	Drain existence	Exists, Not required, Required
	Scouring	None, Slight, Severe
	Blockage	None, Slight, Severe
Shoulder	Side slope condition	No damage, Moderate, Badly Damaged
	Side slope damaged	Area damaged in square metres
	Shoulder condition	No damage, Moderate damage, Severe damage
	Shoulder level	Level or Low, High
Carriageway	Shape	Very Good, Good, Average, Poor, Very Poor, Failed
	Effective width	Length where width has receded by greater than 1 m
	Crown height	As built > 300 mm, 150-300 mm, < 300 mm
	Surface condition	Very Good, Good, Average, Poor, Very Poor
	Ruts	None, < 15 mm, 15 – 30 mm, > 50 mm
	Corrugations	None, < 15 mm, 15 – 30 mm, > 50 mm
	Potholes	None, 1-5, 5-10, >10 per 20 m sub-section
	Loose material	None, < 15 mm, 15 – 30 mm, > 50 mm
	Oversize materials	None, Yes (if 5% of the material > 50 mm)

5. Performance of the Labour-Based Constructed Roads

5.1 Gravel loss

5.1.1 Country-specific results

The height of the road at each cross-section was estimated by taking the average of the readings over the carriageway width at the cross-section. The average height of the site was then determined by taking the average of the 11 cross-sectional heights. The rates of gravel loss on each site were then determined by comparing the average height of the site from each survey. From the various rates determined for each site, a typical rate of gravel loss was selected for each site. These typical rates of gravel loss were usually the maximum rates recorded between two successive surveys on a site in an attempt to exclude the effects of any maintenance that may have been carried out. The observed typical rates of gravel loss for all the sites are listed in Table 5.1.

The observed average rate of gravel loss was lowest in Zimbabwe with a rate of 10 mm/year. The average rate observed in Uganda was 16 mm/year, with the highest rate of 24 mm/year observed in Ghana. However, it should be noted that gravel loss is a function of material and traffic factors, and the impact of these factors on the above gravel loss figures is different in each country.

A more detailed examination of the gravel loss rates was conducted to determine the influence of variables such as traffic and material properties.

The sites were divided into two groups; those with a wearing course that had a low

Figure 5.1
Rates of gravel loss in Ghana

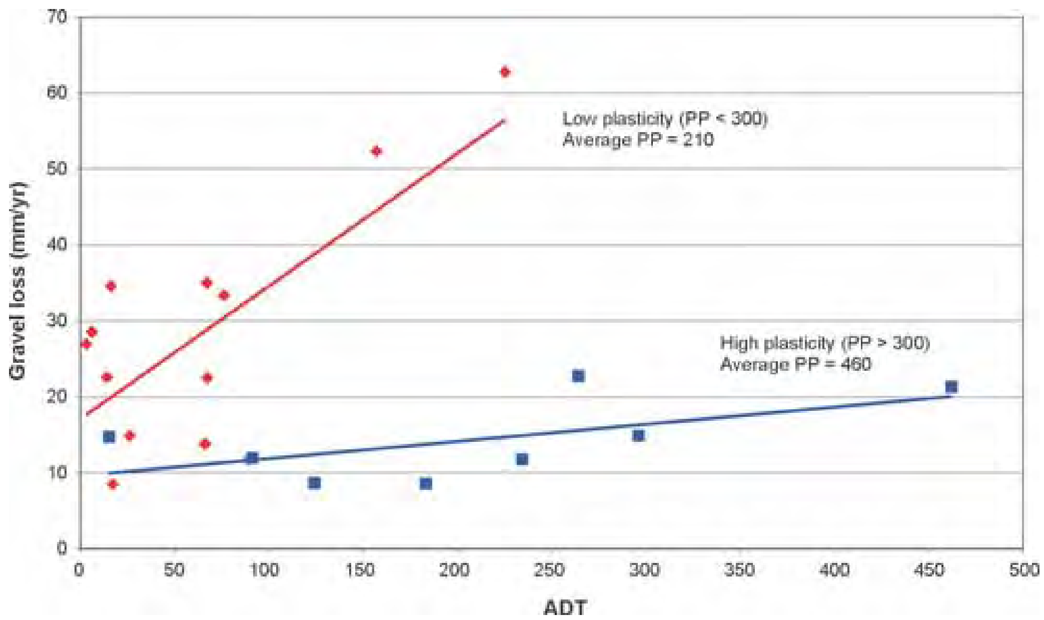


Table 5.1: Observed rates of gravel loss

Zimbabwe		Ghana		Uganda	
Site	Gravel Loss (mm/yr)	Site	Gravel Loss (mm/yr)	Site	Gravel Loss (mm/yr)
CUMA 1	9.7	AIAA	33.4	KAPA	25.4
CUMA 2	18.3	ANAO	14.7	KOMA	12.9
KAME 1	11.3	AOAA	11.8	MAMO	15.5
KAME 2	4.7	AODU	21.3	MOKA	15.7
KAME 3	3.2	AOKM	8.6	MOKO	21.3
MAMI 1	11.1	BACU	35.0	NEKI	12.6
MAMI 2	12.7	BEPO	28.6	NIBU	14.6
MEME 1	13.9	BMBE	8.7	RAKE	10.0
MEME 2	5.6	BNBN	62.8	**Average**	**16.0**
MEME 3	8.6	BNNA	22.7		
MONE 1	19.9	DABI	14.9		
MONE 2	13.2	DACO	36.9		
MSMA 1	13.2	DEWN	12.0		
MSMA 2	10.1	DOKO	52.4		
NACO 1	9.8	FIDA	34.6		
NACO 2	7.0	GNKI	11.8		
NARA 1	7.8	LONM	15.3		
NARA 2	10.6	NALU	27.0		
NUKO 1	16.8	NUSG	30.7		
NUKO 2	15.5	PEYI	13.8		
PESE 1	13.1	SAKE	8.5		
PESE 2	3.6	WAKA	22.5		
SECO 1	9.7	WEPA	15.0		
SECO 2	11.0	ZATE	22.6		
SUMA 1	12.0	**Average**	**23.6**		
SUMA 2	12.9				
TEPU 1	12.2				
TEPU 2	10.0				
TEPU 3	5.8				
TOSA 1	7.9				
TOSA 2	3.7				
Average	**10.5**				

plasticity (Plasticity Product, PP < 300) and those with a high plasticity (PP > 300). The rates of gravel loss for these two groups of sites in Ghana have been plotted against their traffic levels (ADT) in Figure 5.1.

Similarly for the Uganda sites, the rates of gravel loss have been plotted against ADT for sites with low and high plasticity wearing courses as shown in Figure 5.2.

However, for the Zimbabwe sites, no distinct separate trends could be identified between the low and high plasticity sites as shown in Figure 5.3.

Figure 5.2
Rates of gravel loss in Uganda

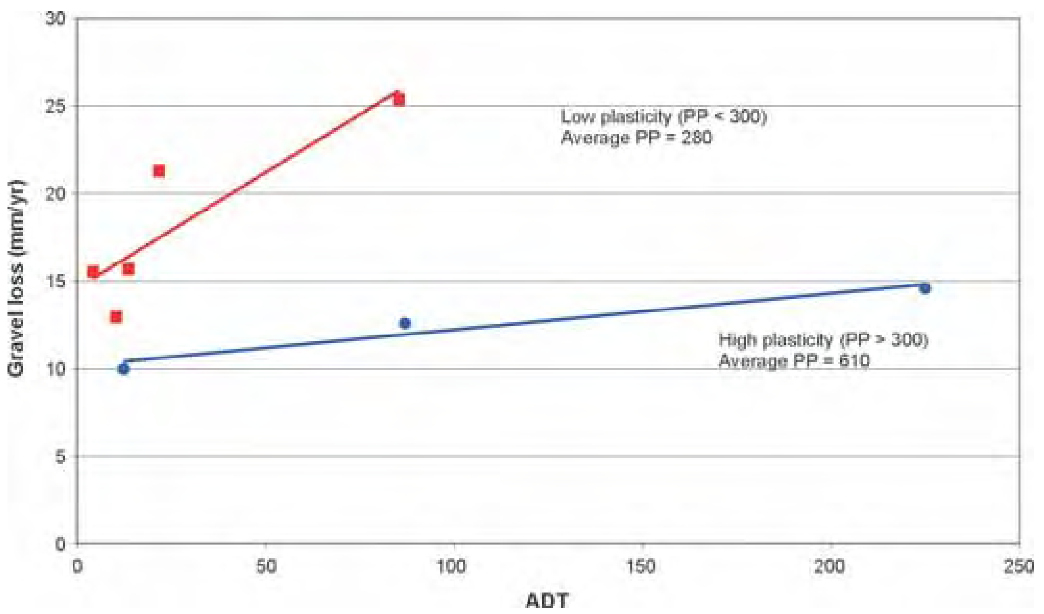


Figure 5.3
Rates of gravel loss in Zimbabwe

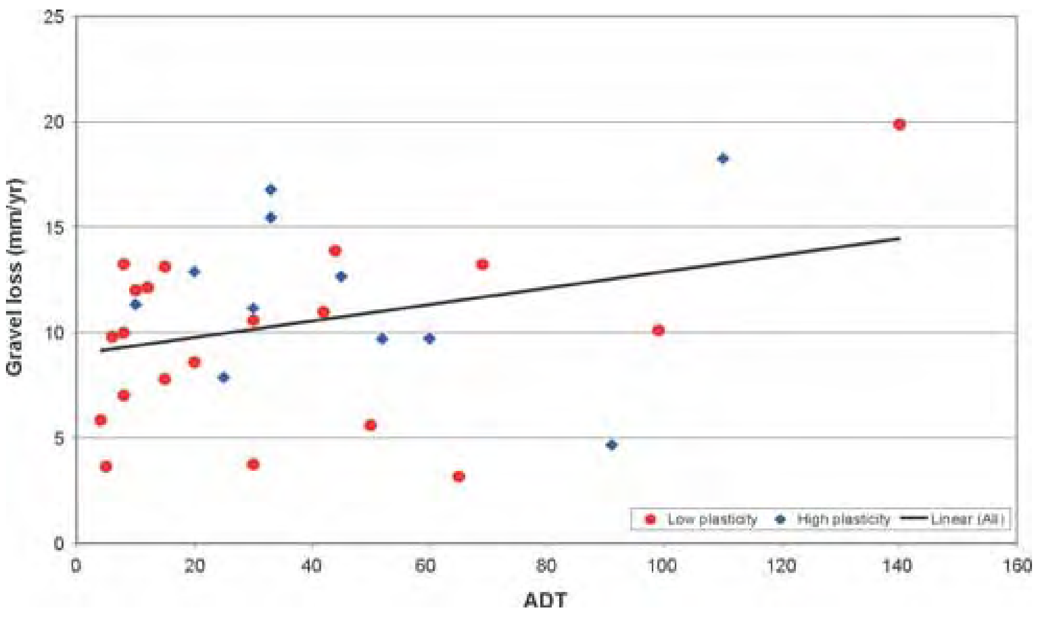


Table 5.2: Gravel loss trends

ADT	Gravel Loss (mm/year)				
	Ghana		Uganda		Zimbabwe
	PP < 300	PP > 300	PP < 300	PP > 300	All
20	21	10	17	10	10
50	26	11	21	11	11
100	35	12	28	12	13
150	43	13	34	13	15
200	52	14	41	14	17
250	61	15	48	15	19

The rates of gravel loss estimated from the trends shown in the above graphs have been given in Table 5.2. These values illustrate the high rates of gravel loss observed on the low plasticity sites compared with the high plasticity sites in both Ghana and Uganda. The rates of gravel loss on the high plasticity sites in these two countries are similar to the average rates observed for all the sites in Zimbabwe.

The figures in Table 5.2 indicate that for gravel roads with a 100 mm thick wearing course, regravelling is required every 3 years for the low plasticity sites carrying approximately 100 vehicles per day (vpd) in Ghana and Uganda, whereas regravelling is required every eight years on the high plasticity sites and in Zimbabwe with similar traffic levels.

5.1.2 Combined results

For the next stage of the analysis, the data from all three studies were combined.

In order to assess the influence of the material properties in more detail, traffic was standardised. Traffic was standardised to 100 vpd and the observed gravel loss was adjusted to correspond to an equivalent gravel loss at an ADT of 100 (GL_{100}).

The plots in Figure 5.1, Figure 5.2 and Figure 5.3 illustrate that gravel loss increases linearly with ADT. However, prior to this adjustment, the gravel loss due to environmental factors (GL_E) such as rainfall and wind needs to be taken into account. The minimum observed gravel loss in each country was used as an estimate of GL_E for that country. The rate of gravel loss at 100 vpd for each site was then derived using the formula:

$$GL_{100} = (GL - GL_E)(100/ADT) + GL_E \quad \ldots (1)$$

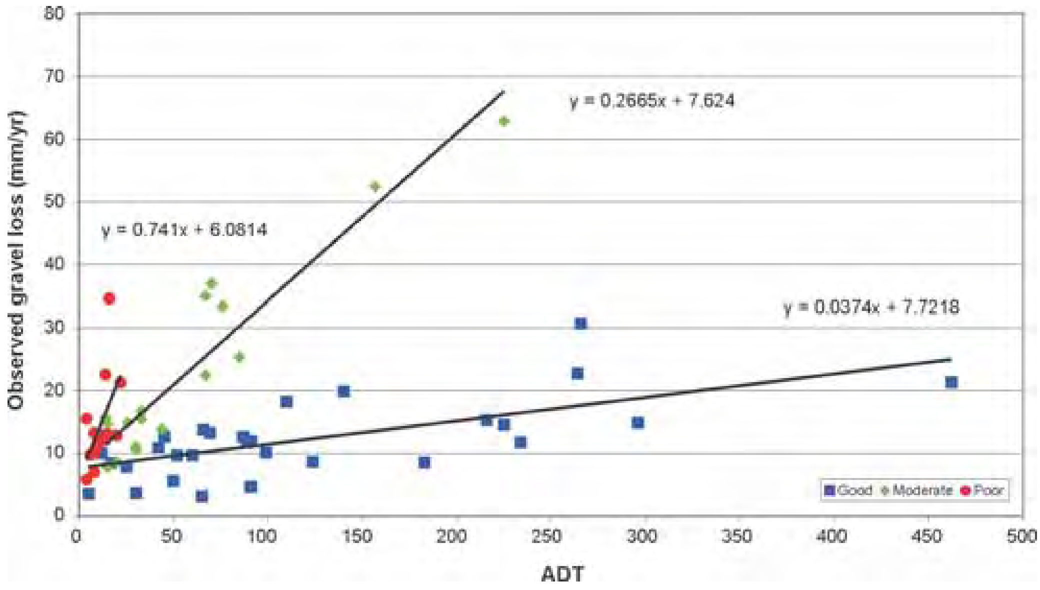
GL_{100} was derived for all the sites and these values of GL_{100} were used to rank the performance of the sites. The performances of the sites were then ranked as 'Good', 'Moderate' or 'Poor' according to their 'standardised' rates of gravel loss (GL_{100}) using the thresholds given in Table 5.3.

Table 5.3: Gravel loss performance criteria

Performance	GL_{100} (mm/year/100 vpd)
Good	≤ 25
Moderate	25 – 50
Poor	> 50

The observed gravel loss on the sites in the three countries have been plotted in Figure 5.4, with each site identified by its gravel loss performance category and with separate trend-lines fitted for each category.

Figure 5.4
Observed gravel loss by performance category



The plot in Figure 5.4 illustrates that the trend-lines converge to a gravel loss of approximately 7mm ± 1mm. This indicates that the environmental contribution to gravel loss is significant at 7 mm/year and is consistent for the three performance categories.

Detailed descriptions of the performances of the individual sites were documented in the appropriate country reports. These assessments indicated that material properties, primarily grading and plasticity, were important factors in the performance of the sites, with the rates of gravel loss generally lower on sites that had a gravel wearing course that was fine with high plasticity.

The quality of the gravel wearing course can be assigned to one of four 'material quality zones', as illustrated in Figure 5.5. The higher quality materials (fine material with high plasticity) are represented by Zone A, where PP > 280 and GM < 1.9. Sites with this high material quality would be expected to perform well. The lower quality material is represented by Zone D, where PP < 280 and GM > 1.9. Sites with this low quality material would be expected to perform poorly, with Zones B and C representing material of marginal quality.

The plasticity product (PP) has been plotted against the grading modulus (GM) for each site in Figure 5.5. In this plot the sites have been identified by their gravel loss performance category as listed in Table 5.3. Zone A (i.e. high quality material) contained sites whose performances have been categorised as either Good or Moderate. The majority of the Poor performing sites were in Zone D (i.e. low quality material), whereas Zones B and C (i.e. marginal quality material) having similar proportions of all three performance category sites.

These findings support the hypothesis that sites in Zone A are likely to perform well, marginally in Zones B and C, and poorly in Zone D.

For the next stage of the analysis process, the representative rate of gravel loss for each material quality zone was determined. The 'standardised' rates of gravel loss (i.e. GL_{100}) of all the sites in each Zone were plotted in a cumulative frequency graph, as shown in Figure 5.6.

Figure 5.5
Gravel loss performance categories vs material quality zones

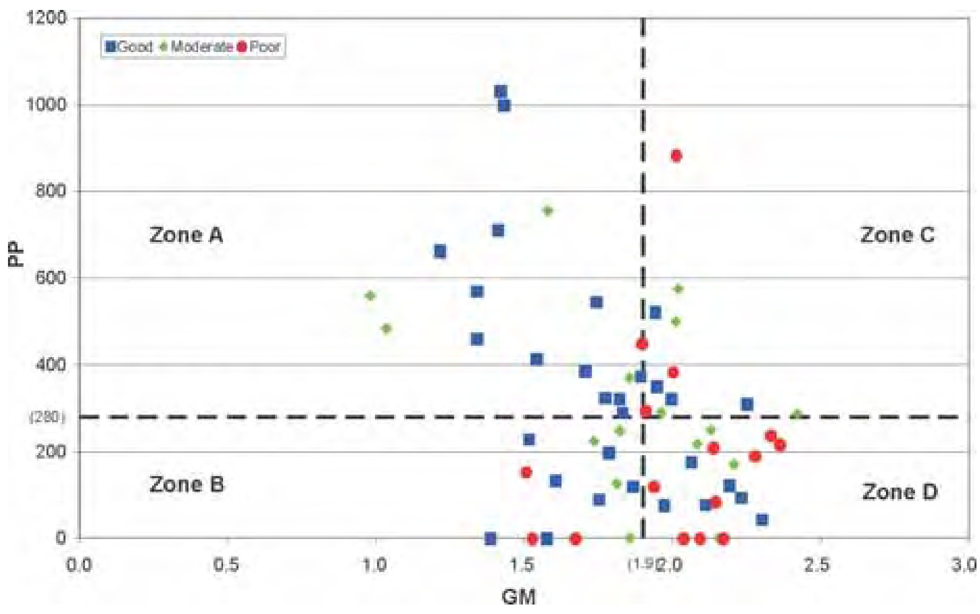
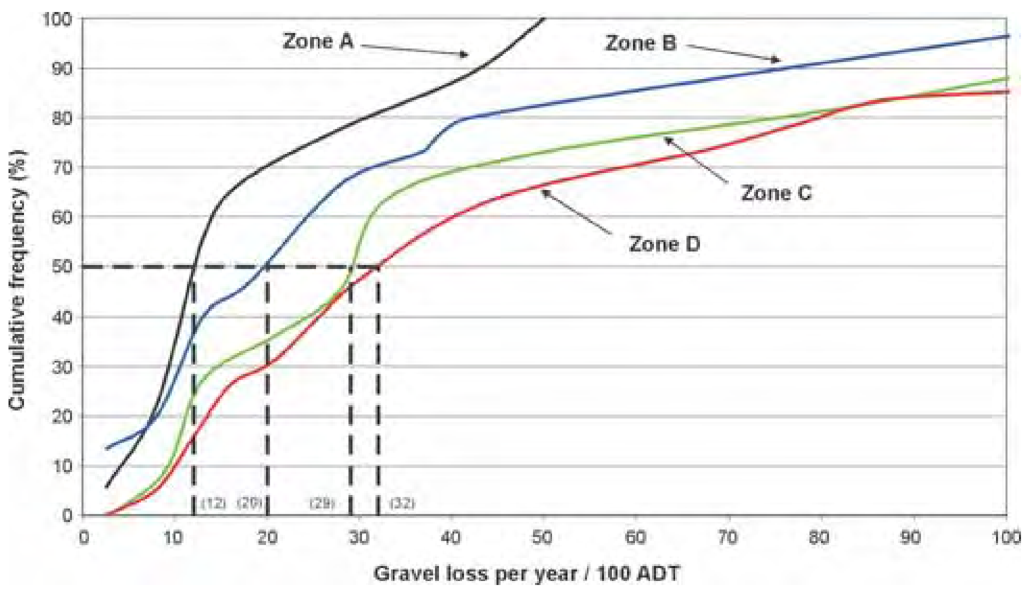


Figure 5.6
Cumulative frequency of standardised rates of gravel loss



The 50 percentile values were taken as the representative rates of GL_{100} for each Zone. These values are listed in Table 5.4.

Table 5.4: Representative rates of gravel loss

Material Quality Zone	Representative Rate of Gravel Loss GL_{100} (mm/yr/100 vpd)
A	12
B	20
C	29
D	32

These values indicate that sites with a gravel wearing course with material properties in Zone A are likely to lose 12 mm/yr when the ADT is 100, whereas for Zone D material, the rate of gravel loss is a factor of 3 times higher for similar traffic levels. The reason behind this could be that bonding is more enhanced in fine materials through the increased surface contact in situations where plastic materials exist in the matrix. Coarser materials, however, tend to have less contact area and where the coarse aggregate is surrounded by fines the larger particles get knocked off as a result of wheel impact – this is usually evident as these larger particles accumulate on road shoulders into windrows.

The results also indicate that the grading of the material has a stronger influence on gravel loss than the plasticity of the material. The rates of gravel loss for sites with wearing course material that was coarse (i.e. Zones C & D) were on average significantly higher than for sites with fine material (Zones A & B), with plasticity having a less significant effect.

5.2 Roughness

5.2.1 Country-specific results

The roughness trends observed on the test sites have been plotted and described in detail in the relevant country reports. The average roughness over the monitoring period observed on each site has been listed in Table 5.5. These values indicate that the average roughness of the sites in Ghana and in Uganda were similar at 6 IRI, whereas the sites in Zimbabwe were, on average, in a poorer condition with an average roughness of approximately 10 IRI.

The rates of roughness progression between surveys on each site were examined. Roughness on unsealed roads can be variable over short periods of time. Decreases in roughness are caused by routine maintenance activities such as spot regravelling or grading. Also, vehicles tend to travel on the least rough areas of the carriageway. Therefore when roughness is measured in the wheelpaths, as in this project, then decreases in roughness may be recorded simply due to vehicles travelling in different wheelpaths.

For these reasons, positive rates of roughness progression were not recorded on a few sites. For the other sites, the observed rates of roughness progressions have been listed in Table 5.6.

The average rates of roughness progression observed in Ghana and in Uganda were similar at approximately 3 IRI/year, whereas in Zimbabwe the average rate was lower at 2 IRI/year, despite the average roughness values in Zimbabwe being higher than in the other two countries (see Table 5.5).

5.2.2 Combined results

As for gravel loss, the data from all three studies were combined for the next stage of the roughness analysis.

The rates of roughness progression were standardised to a traffic level of 100 vpd. However, because of the fluctuations in roughness on unsealed roads (as discussed earlier), no environmental component could be determined. Thus the rate of roughness progression per 100 vpd (IRI/year/100 vpd – IRI_{100}) was determined as a simple ratio of the observed rate of progression (IRI/year - IRI_{obs}) as follows:

$$IRI_{100} = IRI_{obs}(100/ADT) \qquad \text{. . . (2)}$$

Table 5.5: Observed average roughness

Zimbabwe		Ghana		Uganda	
Site	Average Roughness (IRI)	Site	Average Roughness (IRI)	Site	Average Roughness (IRI)
CUMA 1	9.9	AIAA	6.1	KAPA	5.0
CUMA 2	12.7	ANAO	4.2	KOMA	8.4
KAME 1	9.3	AOAA	5.7	MAMO	10.3
KAME 2	8.5	AODU	5.8	MOKA	3.7
KAME 3	12.7	AOKM	6.8	MOKO	4.9
MAMI 1	7.7	BACU	4.7	NEKI	4.9
MAMI 2	8.8	BEPO	5.5	NIBU	6.3
MEME 1	10.1	BMBE	4.5	RAKE	5.0
MEME 2	10.8	BNBN	10.0	**Average**	**6.0**
MEME 3	10.9	BNNA	7.4		
MONE 1	9.8	DABI	4.1		
MONE 2	7.7	DACO	7.4		
MSMA 1	9.3	DEWN	8.1		
MSMA 2	7.2	DOKO	8.1		
NACO 1	7.7	FIDA	4.2		
NACO 2	8.2	GNKI	4.1		
NARA 1	8.0	LONM	9.3		
NARA 2	11.6	NALU	6.6		
NUKO 1	13.1	NUSG	4.4		
NUKO 2	10.8	PEYI	3.7		
PESE 1	10.7	SAKE	4.3		
PESE 2	8.5	WAKA	5.8		
SECO 1	9.9	WEPA	7.5		
SECO 2	11.2	ZATE	4.3		
SUMA 1	7.3	**Average**	**5.9**		
SUMA 2	9.7				
TEPU 1	8.7				
TEPU 2	12.0				
TEPU 3	10.7				
TOSA 1	7.9				
TOSA 2	8.8				
Average	**9.7**				

Table 5.6: Observed rates of roughness progression

Zimbabwe		Ghana		Uganda	
Site	Roughness Progression (IRI/yr)	Site	Roughness Progression (IRI/yr)	Site	Roughness Progression (IRI/yr)
CUMA 1	2.0	AIAA	1.3	KAPA	9.5
CUMA 2	2.6	ANAO	0.4	KOMA	2.1
KAME 1	0.8	AOAA	2.2	MAMO	3.9
KAME 2	n/a	AODU	3.7	MOKA	0.6
KAME 3	2.2	AOKM	3.9	MOKO	2.9
MAMI 1	n/a	BACU	2.7	NEKI	2.7
MAMI 2	0.5	BEPO	2.2	NIBU	2.7
MEME 1	3.2	BMBE	0.1	RAKE	1.8
MEME 2	0.6	BNBN	8.3	**Average**	**3.3**
MEME 3	0.1	BNNA	1.8		
MONE 1	1.8	DABI	1.4		
MONE 2	2.2	DACO	0.1		
MSMA 1	n/a	DEWN	1.6		
MSMA 2	n/a	DOKO	4.5		
NACO 1	2.2	FIDA	7.2		
NACO 2	2.9	GNKI	1.2		
NARA 1	8.1	LONM	5.4		
NARA 2	1.6	NALU	n/a		
NUKO 1	1.8	NUSG	5.0		
NUKO 2	3.4	PEYI	3.4		
PESE 1	2.9	SAKE	1.8		
PESE 2	0.6	WAKA	5.4		
SECO 1	2.7	WEPA	6.3		
SECO 2	0.3	ZATE	4.0		
SUMA 1	0.3	**Average**	**3.2**		
SUMA 2	1.1				
TEPU 1	1.7				
TEPU 2	0.7				
TEPU 3	n/a				
TOSA 1	0.6				
TOSA 2	5.5				
Average	**2.0**				

Notes n/a – positive rates of roughness progression not recorded on these sites

The performances of the sites were then ranked as 'Good', 'Moderate' or 'Poor' according to their 'standardised' rates of roughness progression (IRI_{100}) using the thresholds given in Table 5.7.

Table 5.7: Roughness performance Criteria

Performance	IRI_{100} (IRI/year/100 vpd)
Good	≤ 3
Moderate	3 – 6
Poor	> 6

The observed rates of roughness progression on the sites in the three countries have been plotted in Figure 5.7, with each site identified by its roughness performance category and with separate trend-lines fitted for each category.

The trend-lines for the three roughness performance categories illustrated in Figure 5.7 converge to a roughness of < 1 IRI/year. As this level of roughness progression can be regarded as relatively insignificant for unsealed roads, the environmental contribution to roughness progression was assumed to be negligible.

Using the same four material quality zones as for gravel loss, the sites have been identified by their roughness performance category as illustrated in Figure 5.8. As for gravel loss, Zone A had proportionally more of the better performing sites, whereas Zone D contained the majority of the Poor performing sites.

The representative rate of roughness progression for each material quality zone was determined by plotting the 'standardised' rates of roughness progression (i.e. IRI_{100}) of all the sites within each Zone in a cumulative frequency graph, as shown in Figure 5.9.

Figure 5.7
Observed rates of roughness progression by performance category

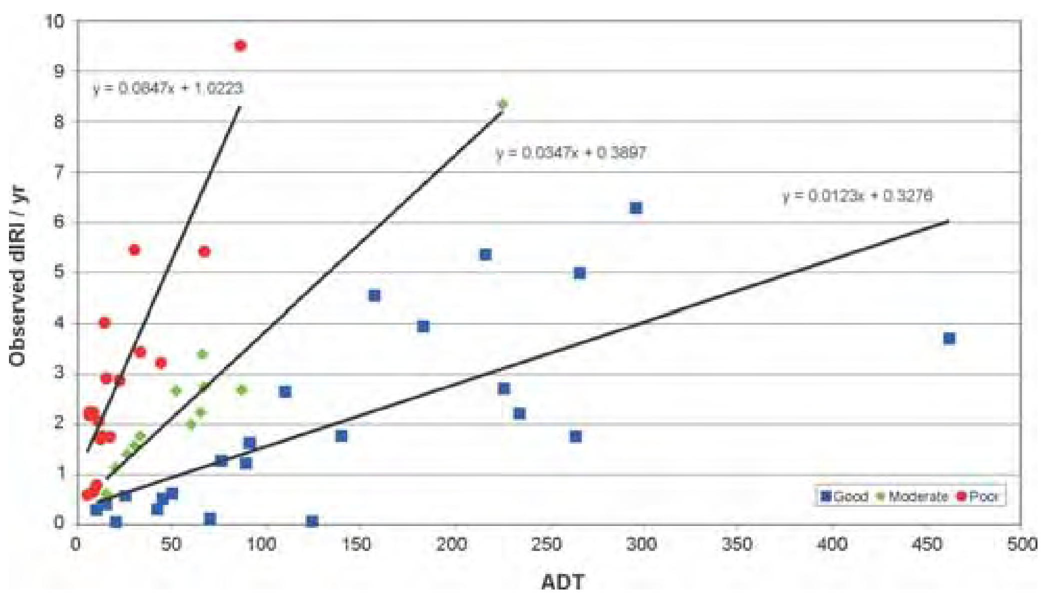


Figure 5.8
Roughness performance categories vs material quality zones

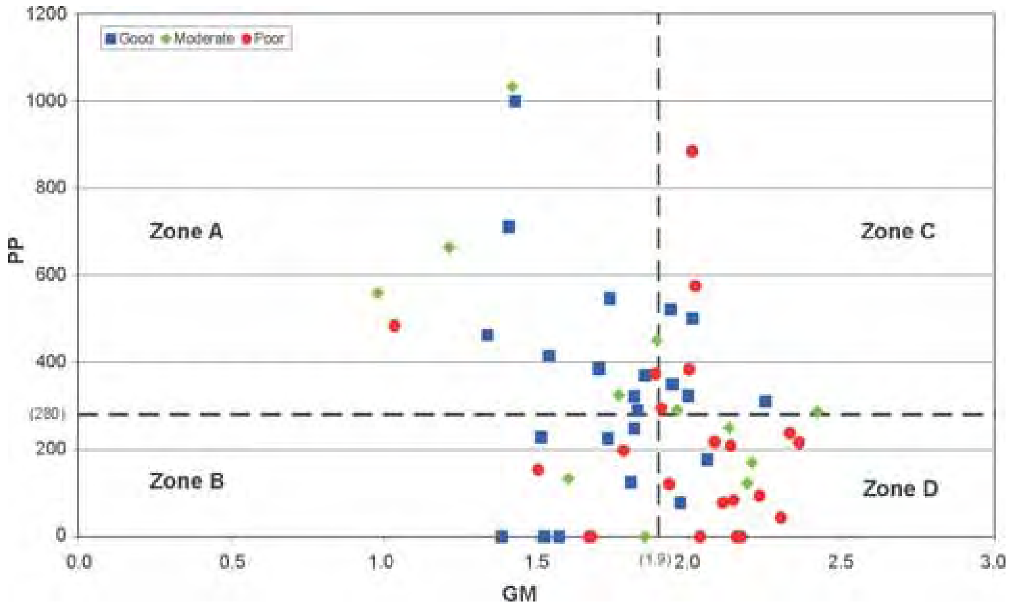
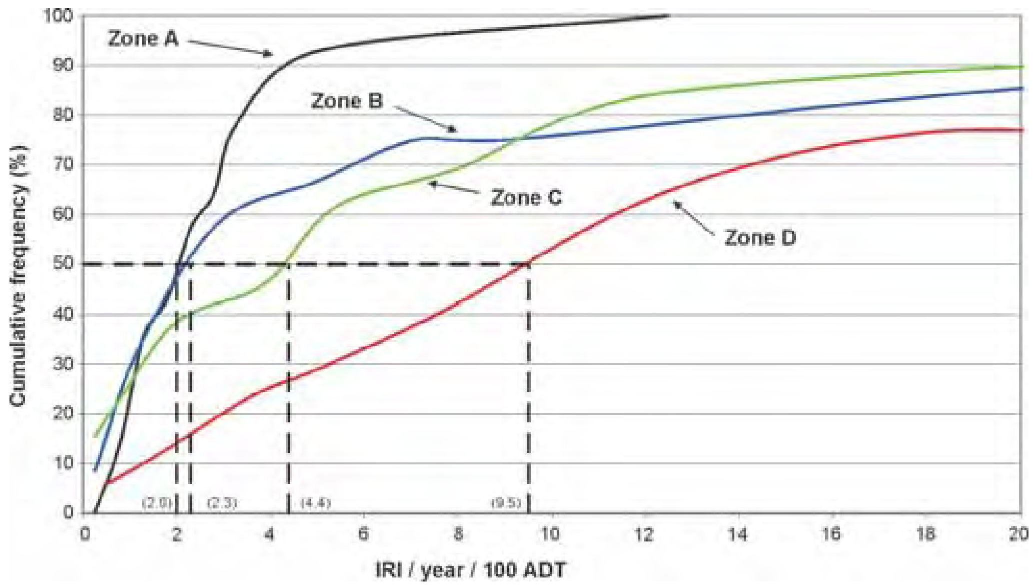


Figure 5.9
Cumulative frequency of standardised rates of roughness progression



The 50 percentile values were taken as the representative rates of IRI_{100} for each Zone. These values are listed in Table 5.8.

Table 5.8: Representative rates of roughness progression

Material Quality Zone	Representative Rate of Roughness Progression IRI_{100} (IRI/yr/100 vpd)
A	2.0
B	2.3
C	4.4
D	9.5

These values indicate that sites with a gravel wearing course with material properties in Zone A are likely to increase in roughness by 2 IRI/year when the ADT is 100, whereas for Zone D material, the rate of roughness progression is almost 5 times faster for similar traffic levels.

6. Comparison with HDM-4 Models

One of the objectives of this project was to compare the observed rates of deterioration on the test sites with those predicted by HDM-4. For unsealed roads, HDM-4 predicts the rate of gravel loss and the rate of roughness progression. A comparison between these predicted rates and those observed on the test sites is described below.

6.1 Gravel loss

Regravelling is the major maintenance operation on unsealed roads, analogous in importance to the overlaying of a paved road, so the frequency required is an important planning decision. Gravel loss is defined as the change in gravel thickness over a period of time and is used to estimate when the thickness of the gravel wearing course has decreased to a level where regravelling is necessary.

The HDM-4 relationship for predicting the annual quantity of gravel loss is a function of rainfall, traffic volume, road geometry and characteristics of the gravel and is given below.

$$GL = K_{gl}\ 3.65\ [3.46 + 0.246(MMP/1000)(RF) + (KT)(AADT)]$$

where

$$KT = K_{kt} \max [0, 0.022 + 0.969(HC/57300) + 0.00342(MMP/1000)(P075) - 0.0092 (MMP/1000)(PI) – 0.101(MMP/1000)]$$

and

GL = annual material loss, in mm/year

KT = traffic-induced material whip-off coefficient

AADT = annual average daily traffic, in vehicles per day

MMP = mean monthly precipitation, in mm/month

RF = average rise plus fall of the road, in m/km

HC = average horizontal curvature of the road, in deg/km

P075 = amount of material passing the 0.075 mm sieve, in % by mass

PI = plasticity index of the material, in %

K_{gl} = calibration factor for material loss

K_{kt} = calibration factor for traffic-induced material whip-off coefficient

The rates of material loss predicted by the above relationship have been illustrated in Figure 6.1 for a range of traffic levels and rainfall for an unsealed road in flat terrain.

The HDM-4 predicted rates of gravel loss for the sites were compared with the rates of gravel loss observed on the sites. The HDM-4 model was then calibrated so that the predicted rate matched the observed rate on each site. As discussed in Section 5.1, for the sites in Ghana and Uganda, two distinct rates of gravel loss were observed, one for sites with low plasticity and one for sites with high plasticity. In Zimbabwe no distinction could be determined between sites with low or high plasticity. The results of this calibration for the individual sites in each country are detailed in the relevant country reports and summarised in Table 6.1.

The default value of the calibration factor for gravel loss, K_{gl}, in HDM-4 is 1.0. The values of K_{gl} in Table 6.1 indicate that on average, the gravel loss observed on the sites in Ghana was approximately 50% higher than predicted by HDM-4 for the conditions (rainfall, traffic, material

Figure 6.1
HDM-4 predicted rates of gravel loss

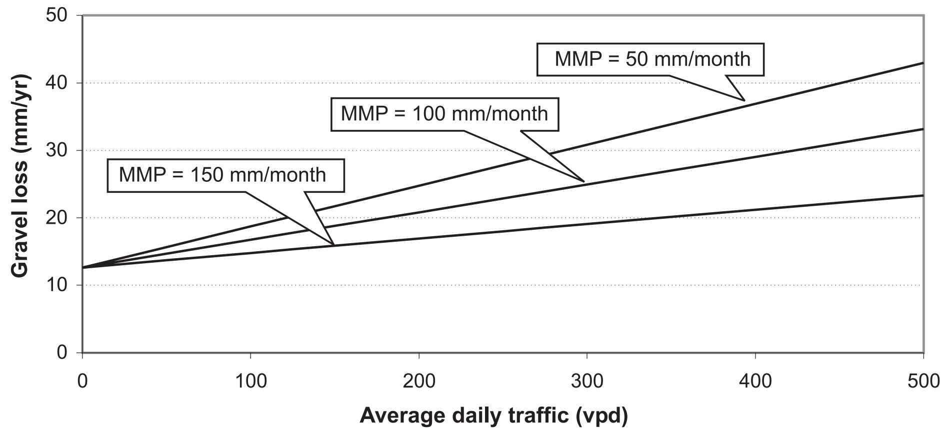


Table 6.1: Average country-specific gravel loss calibration factors

Country	Sites	Calibration Factor K_{gl}
Ghana	Low plasticity	2.43
	High plasticity	0.86
	All	1.51
Uganda	Low plasticity	1.41
	High plasticity	0.80
	All	1.18
Zimbabwe	All	0.65

properties) encountered in Ghana. Similarly, the gravel loss observed on the sites in Uganda were approximately 20% higher than predicted by HDM-4, whereas in Zimbabwe the observed rates were on average some 35% below the HDM-4 predicted values.

In both Ghana and Uganda the values of K_{gl} were significantly higher for the low plasticity sites than for the high plasticity sites, indicating that the observed rates of gravel loss in these countries were more sensitive to plasticity than indicated by the HDM-4 model.

As described in Section 5, the sites were grouped into four material quality zones and the performance of each group of sites was examined. The average value of Kgl for all the sites in each zone was derived and these 'representative' gravel loss calibration factors have been listed in Table 6.2.

Table 6.2: Representative gravel loss calibration factors

Material Quality Zone	Representative Gravel Loss Calibration Factor K_{gl}
A	0.78
B	0.90
C	1.22
D	1.31

The values of K_{gl} in Table 6.2 indicate that HDM-4 predicts higher rates of gravel loss than were observed on sites with fine wearing course material (Zones A & B), whereas for the sites with coarse material (Zones C & D), HDM-4 predicted lower rates of gravel loss than were observed.

6.2 Roughness

In HDM-4, the roughness progression relationship constrains the roughness to a high upper limit, or maximum roughness (RI_{max}), by a convex function in which the rate of progression decreases linearly with roughness to zero at RI_{max} as illustrated in Figure 6.2.

The maximum roughness is a function of material properties and road geometry. The rate of roughness progression is a function of the existing roughness, maximum roughness, time, traffic and material properties. The roughness progression relationship is given by:

$$RI_{TG2} = RI_{max} - b\,[RI_{max} - RI_{TG1}]$$

where

RI_{max} = max{[21.5 – 32.4(0.5 - MGD)^2 + 0.017(HC) – 0.764(RF)(MMP/1000)], 11.5}

b = exp [c(TG2 – TG1)]   where $0 < b < 1$

c = - 0.001 K_c [0.461 + 0.0174 (ADL) + 0.0114(ADH) - 0.0287(ADT)(MMP/1000)]

and

RI_{TG1} = roughness at time TG_1, in m/km IRI

RI_{TG2} = roughness at time TG_2, in m/km IRI

RI_{max} = maximum allowable roughness for specified material, in m/km IRI

TG_1, TG_2 = time elapsed since latest grading, in days

ADL = average daily light traffic (GVW < 3500kg) in both directions, in vehicles per day

ADH = average daily heavy traffic (GVW ≥ 3500kg) in both directions, in vehicles per day

ADT = average daily vehicular traffic in both directions, in vehicles per day

MMP = mean monthly precipitation, in mm/month

HC = average horizontal curvature of the road, in deg/km

RF = average rise plus fall of the road, in m/km

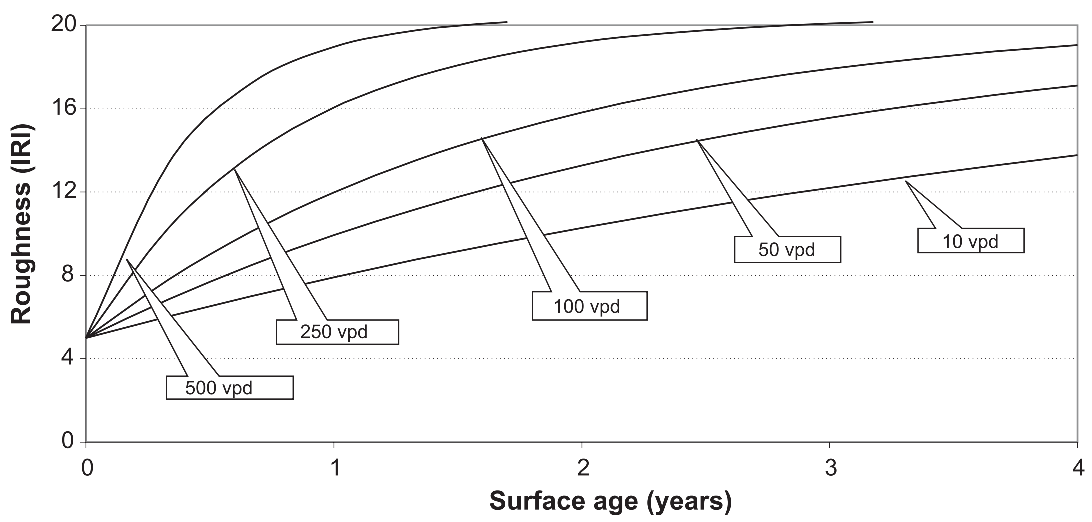
MGD = material gradation dust ratio
= P075 / P425   if P425 > 0
= 1   if P425 = 0

P425 = amount of material passing the 0.425 mm sieve, in % by mass

P075 = amount of material passing the 0.075 mm sieve, in % by mass

K_c = calibration factor for roughness progression

Figure 6.2
Roughness progressions on unsealed roads with no maintenance



The roughness progression relationship given above was derived using observations from roads under repeated grading cycles with no special compaction. The rates of roughness progression after construction or rehabilitation with full mechanical shaping and compaction were observed to be much slower than given by this model.

Thus if "mechanical compaction" is used, the coefficient c is reduced, initially to one quarter of its predicted value and rising to the full predicted value after a few grading cycles, but in a period not exceeding 4 years, as follows:

$$c' = c\ \{\min [1, 0.25(t) \max (1, n^{0.33})]\}$$

where

t = time since regravelling or construction with mechanical compaction, in years

n = frequency of grading, in cycles/year

and

$$b' = \exp[365(c'/n)]$$

When mechanical compaction is specified, then b′ and c′ are used in place of b and c respectively in the roughness progression relationship.

Maintenance, in the form of grading, on unsealed roads tends to reduce the level of roughness. The HDM-4 relationship for predicting this reduction in roughness is a function of the roughness before grading, the material properties and the minimum roughness (RI_{min}). The minimum roughness, below which grading cannot reduce roughness, increases as the maximum particle size increases and the gradation of the surfacing material worsens.

The HDM-4 relationship for predicting the roughness after grading is expressed as a linear function of the roughness before grading, dust ratio and the minimum roughness, as follows:

$$RI_{ag} = RI_{min} + a\ [RI_{bg} - RI_{min}]$$

where

$$a = K_a \max\{0.5, \min [GRAD\ [0.553 + 0.23(MGD)], 1]\}$$

$$RI_{min} = \max \{0.8, \min [7.7, 0.36(D95)(1 - 2.78MG)]\}$$

and

RI_{ag} = roughness after grading, in m/km IRI

RI_{bg} = roughness before grading, in m/km IRI

RI_{min} = minimum allowable roughness after grading, in m/km IRI

D95 = maximum particle size of the material, defined as the equivalent sieve size through which 95% of the material passes, in mm

MG = slope of mean material gradation

MGD = material gradation dust ratio

P02 = amount of material passing the 2.0 mm sieve, in % by mass

GRAD = 1.4 for non-motorised grading, bush or tyre dragging
 = 1.0 for light motorised grading, little or no water and no roller compaction
 = 0.7 for heavy motorised grading, with water and light roller compaction

K_a = calibration factor for the effect of grading

The slope of mean material gradation is calculated as follows:

$$MG = \min [MGM, (1 - MGM), 0.36]$$

where

$$MGM = (MG075 + MG425) + MG02) / 3$$

$$MG075 = \log_e(P075/95) / \log_e(0.075/D95)$$

$$MG425 = \log_e(P425/95) / \log_e(0.425/D95)$$

$$MG02 = \log_e(P02/95) / \log_e(2.0/D95)$$

The HDM-4 predicted rates of roughness for the sites were compared with the roughness observed on the sites. It was assumed that light motorised grading with little or no water and no roller compaction was used on an annual basis (i.e. GRAD = 1.0). The HDM-4 roughness model was then calibrated so that the predicted roughness matched the average roughness observed on the site during the two-year monitoring period. The results of this calibration for the individual sites in each country are detailed in the relevant country reports.

The default value of the calibration factor for roughness progression, K_c, in HDM-4 is 1.0. The average value of K_c derived for each country was 0.6, 0.8 and 0.9 for Ghana, Uganda and Zimbabwe respectively. This indicates that the rates of roughness progression observed on the sites were on average lower than those predicted by HDM-4.

As described in Section 5, the sites were grouped into four material quality zones and the performance of each group of sites was examined. The average value of K_c for all the sites in each zone was derived and these 'representative' roughness progression calibration factors are listed in Table 6.3.

Table 6.3: Representative roughness progression calibration factors

Material Quality Zone	Representative Roughness Progression Calibration Factor K_c
A	0.34
B	0.65
C	1.08
D	1.31

The values of K_c in Table 6.3 indicate that HDM-4 predicts higher rates of roughness progression than were observed on sites with fine wearing course material (Zones A & B), whereas for the sites with coarse material (Zones C & D), HDM-4 predicted lower rates of roughness progression than were observed.

The average material properties of all the sites in each Zone were used as the representative material properties for that Zone in estimating the HDM-4 predicted effect of grading on roughness. The representative material properties for each Zone that are required by HDM-4 are listed in Table 6.4.

These values were used to estimate the roughness after grading (RI_{ag}) using the HDM-4 relationship. As for roughness progression, it was assumed that light motorised grading with little or no water and no roller compaction was used (i.e. GRAD = 1.0). The HDM-4 predicted effect of grading for a range of roughness levels have been tabulated in Table 6.5.

These decreases in roughness due to grading have been used in the life-cycle methodology.

Table 6.4: Representative material properties

Zone	Maximum Particle Size (D95)	Percentage Material Passing 2.0 mm Sieve (P02)	Percentage Material Passing 0.425 mm Sieve (P425)	Percentage Material Passing 0.075 mm Sieve (P075)
A	9.5	61.5	45.0	29.0
B	7.1	73.5	40.8	19.5
C	19.0	47.0	35.0	34.0
D	19.0	47.3	24.8	14.0

Table 6.5: Effect of grading on roughness

Zone	Roughness Before Grading (RI_{bg})	Roughness After Grading (RI_{ag})	Decrease in Roughness Due to Grading(dIRI)
A	6.0	4.5	1.5
	7.0	5.2	1.8
	8.0	5.9	2.1
	9.0	6.6	2.4
	10.0	7.3	2.7
B	6.0	4.2	1.8
	7.0	4.9	2.1
	8.0	5.6	2.4
	9.0	6.2	2.8
	10.0	6.9	3.1
C	6.0	5.1	0.9
	7.0	5.9	1.1
	8.0	6.7	1.3
	9.0	7.4	1.6
	10.0	8.2	1.8
D	6.0	4.4	1.6
	7.0	5.0	2.0
	8.0	5.7	2.3
	9.0	6.4	2.6
	10.0	7.1	2.9

7. Life-Cycle Cost Methodology

The quality of the gravel wearing course on each site has been assigned to one of four 'material quality zones' as illustrated in Figure 7.1. The higher quality materials are represented by Zone A, where PP > 280 and GM < 1.9. Sites with this material quality would be expected to perform well. The low quality material is represented by Zone D, where PP < 280 and GM > 1.9. Sites with this quality material would be expected to perform poorly, with Zones B and C representing material of marginal quality.

The sites from the studies in the three countries (i.e. Ghana, Uganda and Zimbabwe) have been assigned to one of the four 'material quality zones' based on the properties of their gravel wearing course. The performances of the sites were assessed in terms of rates of gravel loss and roughness progression, and representative rates for each Zone were derived (see Table 5.4 for gravel loss and Table 5.8 for roughness progression).

The rates of gravel loss given in Table 5.4 are representative of the rates in each Zone for a traffic level of 100 vpd. These rates can be transformed into rates for different levels of traffic using equation (1) shown in Section 5.1. From these rates, the frequency of regravelling for material in each of the four Zones can be estimated for a range of traffic levels. An example of regravelling to a thickness of 150 mm when the gravel

Figure 7.1
Material quality zones

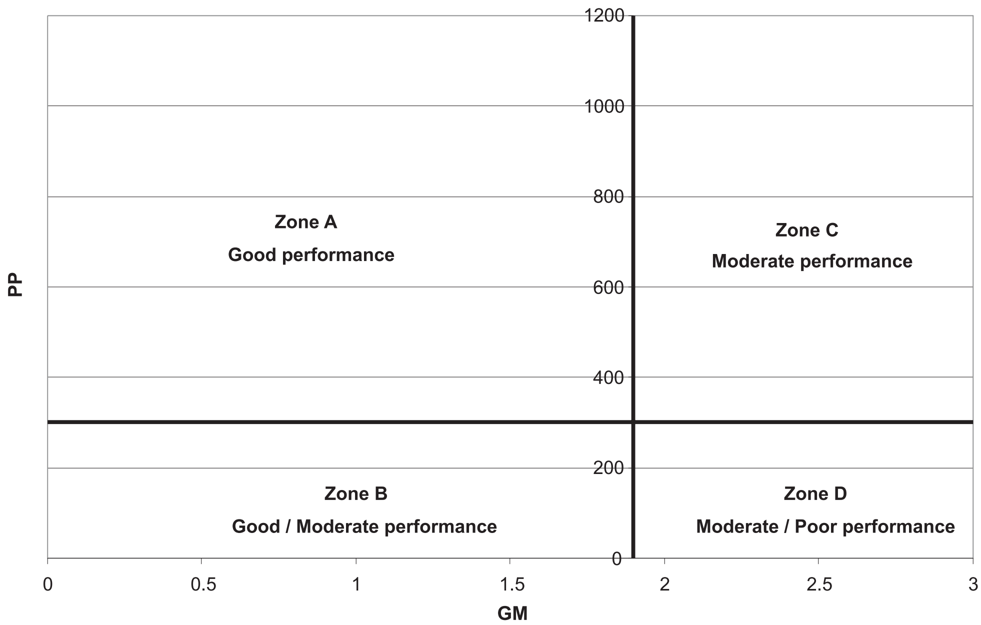
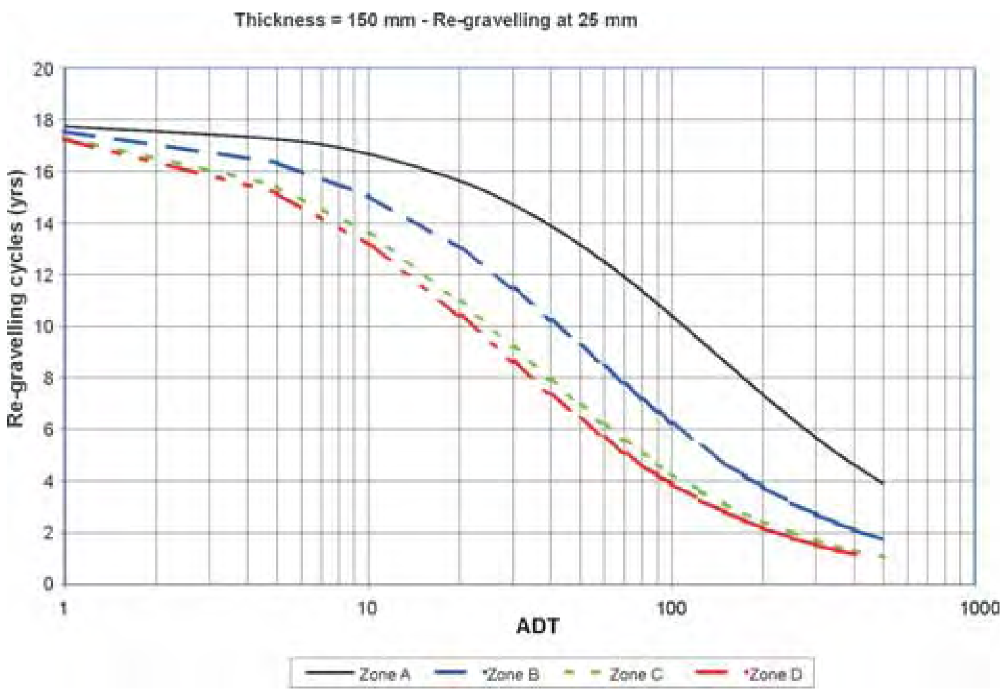


Figure 7.2
Regravelling frequency example



thickness has been reduced to 25 mm has been plotted in Figure 7.2 for traffic levels up to 500 vpd.

This figure shows that for a traffic level of 10 vpd, the regravelling frequency ranges from approximately every 17 years for material in Zone A to every 13 years for material in Zone D. For higher traffic levels of 100 vpd, the regravelling frequency increases to every 10 years for Zone A and every 4 years for Zone D.

Using graphs such as that illustrated in Figure 7.2, the number of times a road will need to be regravelled over its life can be estimated when the quality of the gravel wearing course and the traffic volume is known. The cost of regravelling over the life of the road can then be estimated.

In addition to regravelling costs, life-cycle costs also include initial construction or rehabilitation costs, grading and other routine maintenance costs such as spot regravelling, vegetation control, etc. The frequency of some these routine maintenance activities will depend on perceived acceptable conditions of roads for various levels of traffic. Average figures for routine maintenance can be obtained from historical data or Bill of Quantities or unit rates used by organisations.

The rates of roughness progression given in Table 5.8 are representative of the rates in each Zone for a traffic level of 100 vpd. These rates can be transformed into rates for different levels of traffic using equation (2) shown in Section 5.2.

The effect of grading on roughness has been estimated from HDM-4 for each Zone, as tabulated in Table 6.5. These figures give the reduction in roughness for different levels of roughness intervention levels. From these reductions in roughness and the representative rates of roughness progression, the number of gradings over a period of time can be estimated.

An example of the number of gradings required over a 20-year period using an intervention level of 6 IRI to trigger grading has been plotted in Figure 7.3 for traffic levels up to 500 vpd.

This figure shows that for a traffic level of 100 vpd, the number of gradings over 20 years will be approximately 20 (i.e. once a year) for material in Zone A, increasing to approximately 120 gradings for material in Zone D (i.e. 6 gradings per year), if a grading is triggered whenever the roughness reaches 6 IRI. This is based on principles of performance-based maintenance where desirable or acceptable standards are set beyond which remedial measures should be taken. Performance-based maintenance is becoming more widely used, especially where the use of the private sector is increasingly taking over from force account. The difference in the number of grading for Zone A and Zone D clearly shows how the choice of materials during construction, rehabilitation or regravelling will impact on the future maintenance of the road.

From graphs such as that illustrated in Figure 7.3, the number of times a road will need to be graded over its life can be estimated, knowing the quality of the gravel wearing course and the traffic volume. The cost of grading over the life of the road can then be estimated.

A spreadsheet-based program has been developed for computing life-cycle costs for various levels of traffic and for the different material quality zones as illustrated in the fictitious example in Figure 7.3.

The illustrated example was developed using fictitious unit costs for the construction, regravelling, grading and other routine maintenance activities. The total costs of regravelling and grading were estimated based on the frequency of each activity using graphs such as those illustrated in Figure 7.2 and Figure 7.3.

Figure 7.3
Grading frequency example

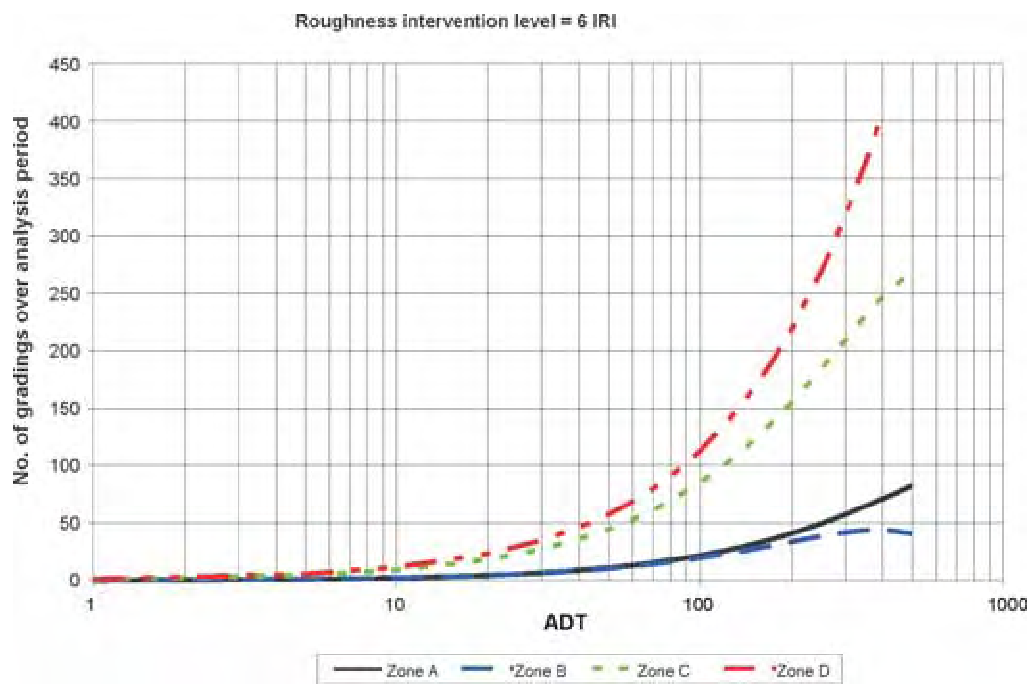
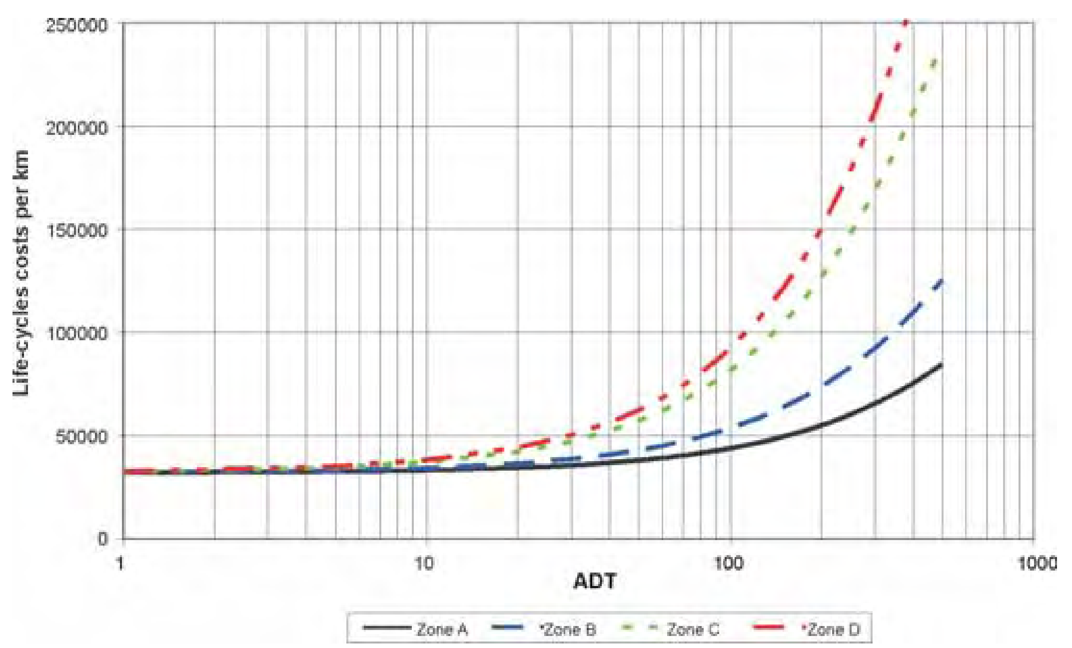


Figure 7.4
Life-cycle cost example



The life-cycle cost calculator requires the following inputs:

- Average Daily Traffic (ADT)
- Currency
- Gravel thickness after regravelling
- Minimum gravel thickness for triggering regravelling
- Cost of regravelling
- Cost of grading
- Cost of other routine maintenance
- Cost of original construction/rehabilitation (optional)
- Life-cycle analysis period
- Roughness after regravelling
- Roughness for triggering grading.

These unit costs, as well as the other parameters will need to be adjusted in the spreadsheet program with country-specific data.

8. Conclusions

The implementation of the outputs and results from this project could have a significant impact on the manner in which labour-based technology is applied and low-volume unpaved roads are managed. The conclusions below put the objectives of the project and the fulfilment of them into perspective.

Deterioration relationships

The deterioration of gravel roads in terms of rates of gravel loss and roughness progression have been investigated and quantified. Material properties and traffic levels have been shown to be highly significant parameters affecting gravel loss and roughness progression.

The plots in Figure 5.4 indicate that at zero traffic the environmental-induced rate of gravel loss is similar for all wearing course materials regardless of material properties. This environmental contribution to gravel loss is 7 mm/year; i.e. 7 mm of gravel is lost each year due to environmental factors, even on roads with zero traffic levels.

The plots in Figure 5.7 indicate that the environmental contribution to roughness progression was negligible.

The quality of the gravel wearing course was assigned to one of four 'material quality zones':

- Zone A (High Quality)
  – PP> 280 and GM < 1.9
- Zone B (High / Marginal Quality)
  – PP < 280 and GM < 1.9
- Zone C (Marginal / Poor Quality)
  – PP > 280 and GM > 1.9
- Zone D (Low Quality)
  – PP < 280 and GM > 1.9

Representative rates of gravel loss were derived for each material quality zone as 12, 20, 29 and 32 mm per year per 100 vpd for Zones A, B, C and D respectively.

Similarly, representative rates of roughness progression were derived for each material quality zone as 2.0, 2.3, 4.4 and 9.5 IRI per year per 100 vpd for Zones A, B, C and D respectively.

The HDM-4 predictive relationships for unsealed roads were compared with the observed rates of gravel loss and roughness progressions. From the comparison, representative calibration factors for the HDM-4 models were derived for each material quality zone.

The representative calibration factors for gravel loss were derived as 0.78, 0.90, 1.22 and 1.33 for Zones A, B, C and D respectively. Similarly, representative calibration factors for roughness progression were derived as 0.34, 0.65, 1.08 and 1.31 for Zones A, B, C and D respectively.

These results mean that HDM-4 can be used with some confidence for predicting rates of deterioration of gravel roads constructed by labour-based methods by using these calibration factors.

Life-Cycle costs

A life-cycle costing methodology has been developed using the results of the observed rates of deterioration. The life-cycle cost tool calculates the agency costs over a period of time. Though there are options to vary the length of the life-cycle of a road, the default suggested is a 20-year period. This is deliberately chosen so that the costs can then be compared with those of sealed roads of similar standards whose design life is commonly accepted to be 20 years.

For each material quality zone, the tool calculates the regravelling frequency based on the representative gravel loss rates derived in this project. User-specified roughness intervention criteria are used to trigger grading activities. The HDM-4 relationship for estimating roughness after grading is used to model the grading effects. The total costs of regravelling and grading over the life-cycle period are then calculated. The costs of other routine maintenance (e.g. spot regravelling, vegetation control, etc.) and original construction costs can also be added.

The tool calculates the total life-cycle agency costs discounted over the analysis period.

Overall project goal and purpose

The goal of this project was 'To promote sustainable livelihoods and contribute to the socio-economic development of disadvantaged rural populations through the provision of improved road access' and the purpose was 'To reduce the life-time costs of unpaved rural roads by promoting appropriate engineering standards, planning tools and works procedures for labour-based construction and maintenance'.

The development of:

i) deterioration relationships for gravel loss and roughness progression based on the quality of the wearing course material
ii) performance related wearing course specifications
iii) a life-cycle costing tool as an aid for planning and designing unpaved roads
iv) the Guideline with quality assurance procedures and specifications including approval of materials and works, and method specifications type of quality control

All contribute towards the fulfilment of the project goal and objective.

The outputs from this project provide road authorities with information and tools for use in the design of rural unpaved roads that are likely to perform well and also assist in estimating the agency costs associated with their sustenance. The use of these outputs gives the hope of improved road access for rural and peri-urban communities, contributing to the sustainable livelihoods and socio-economic development of the disadvantaged populations and the increased application of local resources.

9. Recommendations

The results of this research show that the whole perspective of rural and peri-urban road provision has to change. There are many aspects associated with the output stated above that can make significant differences in the provision of rural roads in the short-, medium- and long-term.

First and foremost, the research findings need to be implemented in order for the benefits to be realised:

1. Policy change: The policies governing the provision of low-volume unpaved roads need to be reviewed. Without this policy review it will be difficult for practitioners to implement on a wide scale. If this does not happen then the benefit will be relatively insignificant.
2. Training of practitioners: Practitioners should be trained on the application of these findings and outputs through short courses in their field of work using their specific projects and real data. This method of training is more effective than formal classroom lectures.
3. Increased awareness: Obviously, training alone could never reach all deserving practitioners and it may be necessary to carry out seminars, workshops, websites, etc. to try and get the information across to as many intended beneficiaries as possible.
4. The life-cycle costing tool should be assessed for applicability in a number of countries. If adopted, a user manual for the life-cycle costing software will need to be produced in order to help the practitioners.
5. Technology choice: In line with increased commitments made at national, regional and global levels on promoting the use of employment-friendly approaches in the delivery and maintenance of infrastructure works, efforts has to be made to translate these commitments into practice. The findings of this research widen the scope for the application of employment-intensive approaches in the road sector.

While the life-cycle costing software provides a tool for estimating agency costs for unpaved roads, it would be advantageous for practitioners to be able to compare the output of life-cycle costs for the gravel option with those of the low-cost sealed roads of the similar standard. This entails determining life-cycle costs for low-cost sealed roads. This will help in setting thresholds on when to upgrade to sealed road standards in order to minimise life-cycle costs.

There is a general bias towards machine-based construction methods because of their use of modern equipment, which gives the perception of better quality products than its labour-based counterpart. One of the anticipated outcomes of this project was the increased application of labour-based technology. Comparisons made in different countries, e.g. Lesotho, Mozambique, South Africa, Tanzania etc. between roads constructed using labour-based and machine-based methods have documented the competitiveness and benefit of labour-based methods. Labour-based methods have proven competitive in terms of technical quality, with the financial and economical cost of construction becoming a catalyst for local economic development.

The Quality Assurance Guideline may need to be streamlined in order to promote its use and thus improve the quality of labour-based works and roads. There is general consensus that there has been little emphasis on quality assurance in the past. The Quality Assurance Guideline will allay client scepticism as to value for money for their investment. Streamlining can be achieved through trialling, awareness, training and dissemination. Trialling is the most crucial part of the process and this can be arranged relatively easily and quickly as there are numerous on-going labour-based works. As this document benefits the clients with good value for money, contractors through speedy and objective approval processes, consultants through simpler quality assurance procedures, designers with design tools and specifications, decision-makers with life-cycle costing information and communities with better and more sustainable roads, etc. stakeholder support for the streamlining process should be forthcoming.