SOUTHERN AFRICAN DEVELOPMENT COMMUNITY
SADC
TOWARDS A COMMON FUTURE

SATCC
SOUTHERN AFRICA TRANSPORT AND COMMUNICATIONS COMMISSION

Guideline

Low-volume Sealed Roads

July 2003

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Foreword

The SADC road network of just over one million kilometres provides the dominant mode of freight and passenger transport and thus plays a vital role in the economy of the region. Unsurfaced low-volume roads constitute a substantial proportion of that network and impact on the lives of the majority of the region's population who live and work in rural areas. Many of these roads are being upgraded to a sealed standard following strategies that focus on poverty alleviation in pursuit of the region's broader goals of socio-economic growth and development.

The main purpose of the Guideline is to provide stakeholders with a synthesis of best regional and international practice in all aspects of low-volume sealed roads. In so doing, it will correct a shortcoming of other available guidelines and manuals that tend to be more narrowly focused on the technical aspects of relatively more heavily trafficked roads and, as a result, have limited applicability to low-volume sealed roads.

Funding for this Guideline has been provided by the UK Department for International Development (DFID), the Norwegian Agency for Development Co-operation (NORAD) and the Swedish International Development Agency (SIDA). These co-operating partners continue to provide development assistance to the region in the transport sector aimed, in part, at improving the sustainability of low-volume sealed roads, coupled with direct poverty alleviation.

By promoting the adoption of a more holistic approach to the provision of low-volume sealed roads and the use of innovative best practice from the region, the Guideline will undoubtedly lead to a more efficient use of available road funding. This will result in direct benefits to all SADC countries and facilitate socio-economic growth and development, leading to a reduction in poverty.

I wish to thank our cooperating partners for co-funding this project as well as the UK Transport Research Laboratory (TRL) and the Norwegian Public Roads Administration (NPRA) for managing it. I also wish to thank all those who contributed their knowledge and experience to enable this Guideline to be produced; in particular, the Lead Authors, representatives from member states who were closely involved in its development and the international panel of experts who reviewed the document. I am convinced that all stakeholders will find the Guideline to be a valuable source of information for the more efficient and effective provision of low-volume sealed roads in the SADC region.

Sakhe Silo
Director - SATCC Technical Unit
Maputo, Mozambique

DFID

NORAD
DIREKTORATET FOR UTVIKLINGSSAMARBEID
NORWEGIAN AGENCY FOR DEVELOPMENT COOPERATION

Sida

Dedication

This guideline is dedicated to the memory of the late Eric Msolomba, former director of the SATCC Technical Unit, whose vision provided the motivation for this project, and whose dedication and leadership made this document possible.

Acknowledgements

The Project Team gratefully acknowledges the contributions and comments received from a large number of professionals representing a wide range of disciplines, in organisations from both the public and private sectors, who participated in the workshops held in connection with the compilation of the Guideline. These organisations included Government ministries (including Roads Departments and Traffic Safety Units), National Roads Authorities, consultants, contractors and materials suppliers. Particular thanks are due to the SATCC Technical Unit, the CSIR and the authors for their contributions and to the Peer Reviewers for their comments on the drafts. Thanks are also due to the workshop facilitators and presenters who also made valuable contributions to the project.

SADC Road Sector Organisations

The high level of support and guidance provided by the road sector organisations in the SADC member states in the development of the Guideline and in the hosting of country workshops is gratefully acknowledged. The following organisations are expected to be the main agencies involved in the implementation of the Guideline:

Angola	Angolan Road Agency (INEA), Ministry of Public Works, Luanda
Botswana	Roads Department, Ministry of Works and Transport, Gaborone
DRC	Office des Routes, Kinshasa/Gombe
Lesotho	Roads Department, Ministry of Public Works and Transport, Maseru
Malawi	National Roads Authority, Lilongwe
Mauritius	Road Development Authority, Ministry of Public Infrastructure, Phoenix
Mozambique	National Roads Administration (ANE), Maputo
Namibia	National Roads Authority, Windhoek
Seychelles	Land Transport Division, Ministry of Transport and Tourism, Mahé
South Africa	South African National Roads Agency (SANRA), Pretoria
Swaziland	Roads Department, Ministry of Public Works and Transport, Mbabane
Tanzania	Tanzania National Roads Agency (TANROADS), Dar es Salaam
Zambia	Roads Department, Ministry of Works and Supply, Lusaka
Zimbabwe	Roads Department, Ministry of Transport, Harare

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A new approach

The successful provision of a low-volume sealed road requires ingenuity, imagination and innovation. It entails "working with nature" and using locally available, non-standard materials and other resources in an optimal and environmentally sustainable manner.

It will rely on planning, design, construction and maintenance techniques that maximize the involvement of local communities and contractors.

When properly engineered, a LVSR will reduce transport costs and, through its impact on rural production and on trade between regions, facilitate socio-economic growth and development and reduce poverty in the SADC region.

Provision of Low-volume sealed roads: Time for a re-think by decision-makers!

Low-volume roads, economic development and poverty alleviation

The criteria for defining a "Low-volume road" varies significantly in various parts of the world. In the SADC region, such roads may be primary, secondary or tertiary/access roads. They typically carry less than 200 vehicles per day, including up to 20% commercial vehicles, and often include non-motorised traffic, particularly near populated areas.

- The majority of rural roads and a significant proportion of the main roads in the SADC region are currently unsurfaced and are relatively lightly trafficked. These low-volume roads are important in that they:
  - impact significantly on the livelihoods of the majority of the population of many countries in the region, who live and work in rural areas where poverty levels are generally very high
  - are central to sustained socio-economic growth and development of the region and are a key component of development programmes targeted by donors and governments in which poverty reduction strategies feature
- Unfortunately, the poor condition of these roads, which can be largely attributed to the way in which they have customarily been provided and maintained, has acted as a brake on economic development and hindered poverty alleviation efforts.
- New, more appropriate, approaches to the provision of low-volume sealed roads (LVSRs) are now required if the region is to improve road transport efficiency and attain its broader goals of socio-economic growth, development and poverty alleviation.

The inappropriateness of traditional methods

- Traditional approaches to the provision of low-volume sealed roads have stemmed from technology and research carried out in Europe and the USA over 40 years ago in very different environments.
- Locally prevailing circumstances are usually very different in terms of climate, traffic, materials and road users. It is therefore not surprising that many of the imported approaches, designs and technologies are inappropriate for application in the region.
- Technology, research and knowledge about LVSRs have advanced significantly in the region and not only question much of the accepted wisdom on LVSR provision but also show quite clearly the need to revise conventional approaches.
- Unfortunately, there has been little effective dissemination and uptake of the results of research carried out in the region. This has triggered the need for this *SADC Guideline on Low-volume Sealed Roads*.

Extensive research has been undertaken in the SADC region over the past 20 - 30 years. This has enabled local, "non-standard" materials to be successfully incorporated in appropriate pavement design for LVSRs.

Unpaved roads generate dust in dry weather causing health hazard, damage to crops, vehicles and natural habitats and adversely affecting the safety of pedestrians and vehicles. Is a sealed surface an affordable option?
Yes! It certainly can be.

A substantial amount of gravel is extracted annually from borrow pits in all countries of the SADC region. Is this sustainable?
No! It is not.

Achieving sustainability in all aspects of LVSR provision is absolutely critical, if the SADC region's long term goals of sustained economic growth and poverty alleviation are to be attained. In the past, attempts to achieve such sustainability have failed because one or more of the seven key dimensions has been missing or inadequate. The result has been that LVSRs have fallen into disrepair and, consequently, have not only failed to serve the needs of the poor but, also, have often adversely affected the environment.

Why sealed roads?

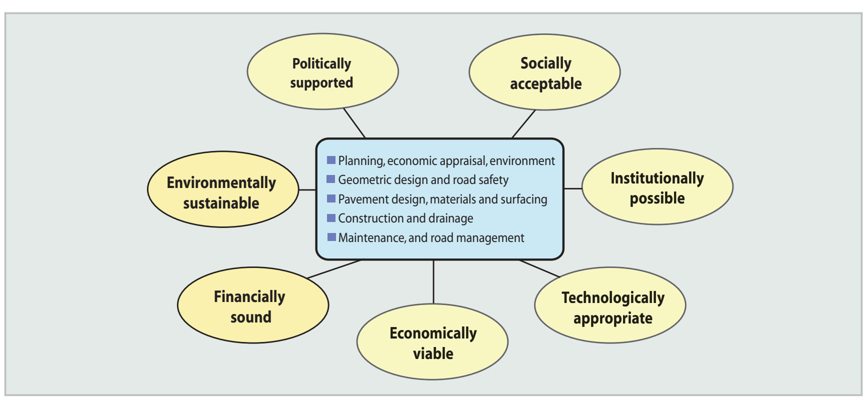
- The substantial length of unsurfaced, particularly gravel, roads in the region is becoming increasingly difficult to sustain in that such roads:
  - impose a logistical, technical and financial burden on most road agencies due to constraints on physical, human, financial and natural resources
  - require the continuous use of a non-renewable resource (gravel) which is being seriously depleted in many countries and, in the process, is causing serious environmental problems
- Implementation of the results of regional research (for example, that reduce construction costs through the increased use of natural gravels), enable the sealing of gravel roads to be economically justified at less than 100 vehicles per day (vpd). This figure is in contrast to the previously recommended threshold values for Sub-Saharan Africa, which were in excess of 200 vpd and is a figure that still persists in the minds of many practitioners.
- Failure to observe the optimal timing for sealing gravel roads can be very costly to national economies, not only in terms of incurring excess transport costs but, also, in the continuing excessive maintenance burden and adverse socio-environmental effects. This provides a strong impetus for policy change and the adoption of alternative, cost-effective, surfacing strategies promoted in this Guideline.

The benefits of sealed roads

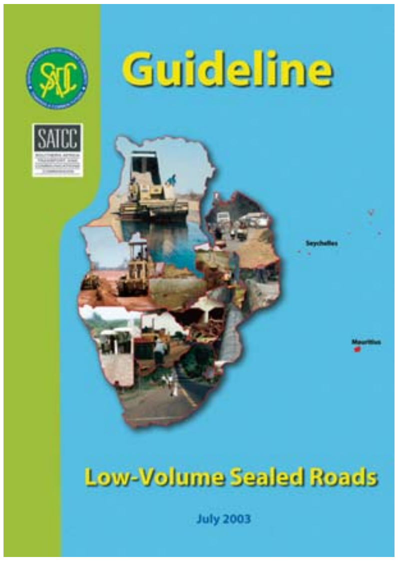
- The whole-life benefits of sealed roads include:
  - lower transport (construction, maintenance and vehicle operating) costs
  - increased social benefits (more reliable access to schools, clinics, etc)
  - reduced adverse environmental impacts and health and safety problems
- Based on a conservative rate of upgrading gravel roads to a sealed standard of 100 km/year, the annual benefits of adopting the recommendations of this Guideline will be of the order of US $35 million.
- The above benefits hinge critically on the ability of the responsible authority to maintain the sealed roads to the level of service for which they were designed. This requires provision of adequate, sustainable and timely funding for the sub-sector which, increasingly, is being provided by road users on a "fee-for-service" basis.

Key dimensions of sustainability

- There has been a tendency to focus predominantly on the technical and economic aspects of LVSR provision and inadequate attention has been given to other aspects of sustainability. The result has often been a lack of responsiveness to various other requirements and a reduced likelihood of achieving sustainable solutions, even when substantial funding is made available.
- The seven key dimensions of a sustainable system, which should always be observed in the provision of LVSRs, are shown below.



- Sustainability in all aspects of LVSR provision should now become the basis of a more demanding policy of SADC governments. This will require that practitioner adopt a more broadly based approach than hitherto that pays full attention to all seven dimensions of sustainability.



Meeting new challenges – the SADC Guideline on LVSRs

- The main objective of the Guideline is to capture best regional and international practice in all aspects of LVSR provision. It is not a prescriptive document but, rather, provides guidance to users so as to ensure that well-considered decisions are made. The development of the Guideline has benefited from the close involvement of practitioners in the region.

- The Guideline presents a major departure from traditional practice in all aspects of LVSR provision by examining procedures, practices and methods used in:
  - planning, appraisal and environment
  - geometric design and road safety
  - pavement design, materials and surfacing
  - construction and drainage
  - maintenance

- The Guideline promotes the use of a holistic approach to LVSR's, which recognizes that criteria need to be satisfied in the different and often interacting dimensions of road provision.

The benefits of using the Guideline

- There are a number of benefits to be derived from adopting the approaches advocated in the Guideline. These include providing LVSRs that:
  - are less expensive in economic terms to build and to maintain through the adoption of more appropriate, locally-derived technology and design/ construction techniques that are better suited to local conditions
  - minimize adverse environmental impacts, particularly as regards the use of non-renewable resources (gravel)
  - increase employment opportunities through the use of more appropriate technology, including the use of labour-based methods, where feasible
  - improve road safety in all aspects of road provision
  - take better account of the needs of all stakeholders, particularly the local communities served by these roads
  - foster local road building and maintenance capacity through the greater use of small-scale, local contractors
  - ultimately, facilitate the longer-term goal of socio-economic growth, development and poverty alleviation in the region

Promotion of labour-based methods where feasible, is a key factor in creating productive employment and reducing poverty.

- In addition to the above, the Guideline will also generate awareness and disseminate the knowledge required if these benefits are to be enjoyed more widely in the region.

Moving from vision to practice

The new idea either finds a champion or dies.....No ordinary involvement with a new idea provides the energy required to cope with the indifference and resistance that major technological change provokes... Champions of new ideas must display persistence and courage of heroic quality.

- The full benefits of the Guideline will be realised only if the approaches recommended are implemented in practice. However, there are a number of barriers which will tend to frustrate this process. These include:
  - an inevitable and natural tendency to resist change and the conservative nature of public-sector organisations which tend to institutionalize this resistance
  - The fact that many of the recommendations contained in the Guideline may be in conflict with existing, often out-dated, country manuals and standards

- Ultimately, the successful move from vision to practice will require endorsement at political level, as well as the full support of all stakeholders. In addition, it will require considerable technology transfer effort including:
  - support and technical assistance to facilitate the implementation of the Guideline
  - updating country documents to suit specific local conditions
  - technical staff training to address potential internal resistance to change
  - careful monitoring of acceptance, adoption, refinement and satisfaction amongst users of the Guideline

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Abbreviations

Organisations

AID	Agency for International Development
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ARRB	Australian Road Research Board
ASIST	Advisory Support Information Services And Training (For Employment-Intensive Infrastructure)
ASTM	American Society for Testing and Materials
CAPSA	Conference on Asphalt Pavements for Southern Africa
CEBTP	Centre Experimental de Recherches et D'etudes du Batiment et des Travaux Publics
CSIR	Council for Scientific and Industrial Research
CSRA	Committee of State Road Officials
DFID	Department for International Development
DLO	Direct Labour Organisations
DoR	Department of Roads
ILO	International Labour Organisation
IRF	International Road Federation
MOW	Ministry of Works
NAASRA	National Association of Australian State Road Authorities
NIRR	National Institute for Road Research
NITRR	National Institute for Transport and Road Research
NORAD	Norwegian Agency for International Development
NPRA	Norwegian Public Roads Administration
NRRL	Norwegian Road Research Laboratory
NSW	New South Wales (Australia)
ODA	Overseas Development Administration
PIARC	Permanent International Association of Road Congresses (World Road Association)
RA Board	Roads Agency Board
RF Board	Road Fund Board
SABITA	Southern Africa Bitumen and Tar Association
SADC	Southern Africa Development Community
SADCC	Southern African Development Coordination Conference
SAICE	South African Institution of Civil Engineering
ATC	Annual Transportation Conference
SANRA	South African National Roads Agency
SATCC	Southern Africa Transport and Communications Commission
SIDA	Swedish International Development Agency
TANROADS	Tanzania National Roads Agency
TRB	Transportation Research Board
TRL	Transport Research Laboratory
TRRL	Transport and Road Research Laboratory
UK	United Kingdom
UN	United Nations
UNESCO	United Nations Educational Scientific & Cultural Organisation
USA	United States of America
WA	Western Australia

Abbreviations

Technical

AADT	Annual Average Daily Traffic
AIV	Aggregate Impact Value
AC	Asphalt Concrete
ACV	Aggregate Crushing Vakue
ADT	Annual Daily Traffic
BCR	Benefit Cost Ratio
BOQ	Bill of Quantities
BS	British Standards
CBA	Cost-benefit analysis
CaSE	Cost and Safety Efficient Design
CBR	California Bearing Ratio
CEO	Chief Executive Officer
DMI	Durability Mill Index
elv	Equivalent Light Vehicles
DCP	Dynamic Cone Penetrometer
E_s	Elastic Stiffness
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
ESA	Equivalent Standards Axle (based on 80 kN standard)
FACT	Fines Aggregate Crushing Test
FMC	Field Moisture Content
FWD	Falling Weight Deflectometer
GDP	Gross Domestic Product
HDM-4	Highway Development and Management Model-4
HIV/AIDS	Human Immune Deficiency Virus/Acquired Immune Deficiency Syndrome
HVR	High-volume road
HVS	Heavy Vehicle Simulator
HVSR	High-volume Sealed Roads
IQL	Information Quality Level
IRAP	Integrated Rural Accessibility Planning
IRI	International Roughness Index
IRR	Internal Rate of Return
KPI's	Key Performance Indicators
LAA	Los Angeles Abrasion
LBM	Labour Based Methods
LVR	Low-volume Road
LVSR	Low-volume Sealed Road
MC	Moisture Content
MDD	Maximum Dry Density
NMT	Non Motorised Traffic
NPV	Net Present Value
OMC	Optimum Moisture Content
ORN	Overseas Road Note (TRL series of publications)
PI	Plasticity Index
PSD	Passing Site Distance
PSV	Polished Stone value
R & W	Riedel and Weber
RED	Road Economic Decision model

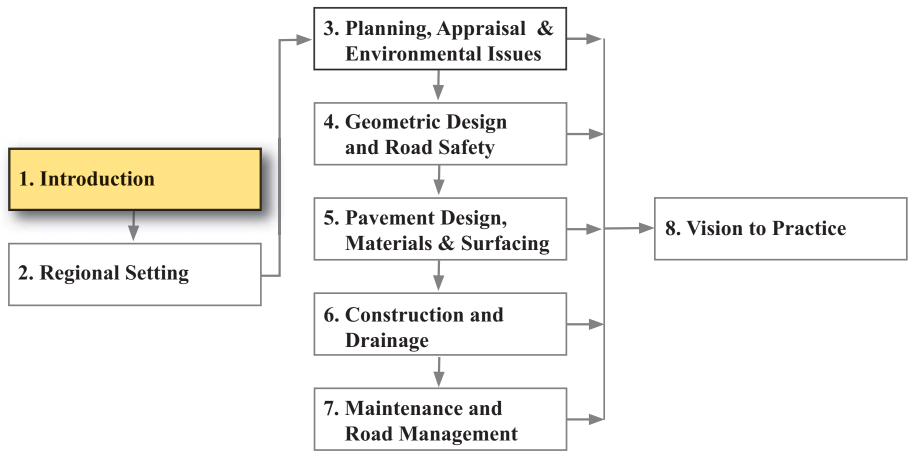
RM	Routine Maintenance
RMI	Road Maintenance Initiative
RMS	Road Management Systems
RTIM	Road Transport Investment Model
RTRN	Regional Trunk Road Network
SAMDM	South African Mechanistic Design Method
SFRDP	Secondary Feeder Road Development Programme
SSATP	Sub-Saharan Africa Transport Program
SSD	Stopping Sight Distance
TBM	Texas Ball Mill
TMH	Technical Methods for Highways
TRH	Technical Recommendations for Highways
TTC	Travel Time Cost
VCI	Visual Condition Index
VOC	Vehicle Operating Costs
vpd	Vehicles per day

Abbreviations

Units

Hr	Hour
Kg	Kilogram
Km, m, cm, mm	Kilometre, metre, centimetre, millimetre
kPa	Kilo-Pascal
kN	Kilo-Newton
Km/h	Kilometre per hour
m^2, m^3	Square metre, cubic metre
Veh-km	Vehicle kilometre
Yr	Year

Chapter 1


1. Introduction
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Introduction

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Introduction

1

"The body of highway engineering knowledge remains empiric rather than rigorously scientific. So, the knowledge taught in our [UK, USA] universities is generally derived from a synthesis of local experience. No wonder it is often irrelevant and sometimes downright misleading in other parts of the world".

Ray Millard, Highways Advisor, World Bank. 2nd Int. Conf. on Low-volume Roads, 1979[1].

1.1 Background

Many aspects of the documentation on low-volume road provision in the SADC region have stemmed from technology and research carried out in Europe and the USA some 30 - 40 years ago in vastly different environments. Although some of this documentation has been modified to some extent in the intervening years, the basic philosophy of road provision has remained essentially the same. Whilst these standard approaches may still be appropriate for the more heavily trafficked SADC trunk road network, they are clearly inappropriate for use on low-volume roads which make up a large proportion of national road networks. This has prompted a number of international research organizations, as well as government departments and local agencies, to undertake research into various aspects of low-volume sealed roads.

Box 1.1 - Road research in the SADC region

Research carried out in the SADC region by a number of international, regional and local organisations, which is conservatively estimated to have cost US $20 - 30 million, has questioned many of the accepted assumptions about the planning, design, construction and maintenance of low-volume sealed roads. This research has quite clearly shown:

- the importance of adopting a more holistic, sustainable approach to the provision of low-volume roads
- the need to revise conventional approaches to planning, economic appraisal and the environment
- the shortcomings of conventional specifications and, to some extent, of test methods, in assessing the adequacy of local materials for use in low-volume roads
- the advantages of adopting more appropriate geometric and pavement design standards
- the economic success of innovative construction methods
- the importance of paying greater attention to the environmental aspects of road provision

Research carried out in the SADC region has catalysed the re-thinking of the whole approach to low-volume sealed roads[2,3,4].

"Probably the most important and critical issue (in technology transfer) is ***information dissemination.*** *Presenting all available and relevant information to practitioners is essential to implementing improved procedures and new techniques. Given the amount of research and development that is still being undertaken, the ability to disseminate this information quickly is the key to advancing the low-volume road situation".*

Transport Research Circular No. 446, May 1995[5].

Unfortunately, because of a lack of funding, there has been very little effective dissemination of the research carried out in the region. This has led to:

- a lack of awareness of the results of research
- a lack of understanding of the often satisfactory performance of innovative solutions
- an aversion to the use of "non-standard" designs, particularly by foreign consultants and contractors who are often unfamiliar with local conditions
- poor technology transfer
- little implementation of innovative technology

In recognition of the need for raising awareness of recent developments in low-volume sealed road technology in the region, the Southern African Transport and Communications Commission (SATCC) commissioned the preparation of this *Guideline on Low-volume Sealed Roads* (LVSRs) which was funded by DFID, NORAD and SIDA.

1.2 Purpose and Scope

The main purpose of the Guideline is to provide a synthesis of practical, state-of-the-art approaches to LVSR provision, based largely on regional knowledge and experience, while taking into account international best practice. In so doing, the primary goal is to reduce the cost of constructing and maintaining LVSRs leading to:

- increased public and commercial transport through lower road user costs
- improved access to schools, clinics, jobs, urban centres and neighbouring rural areas
- improved environmental, health and social conditions
- reduced depletion of finite materials resources - regravelling is an inherently unsustainable activity
- enhanced socio-economic growth, development and poverty alleviation

The means of achieving the above hinges on cost-effective provision of sealed roads in rural and peri-urban areas by the transfer of technology developed through research. The Guideline therefore seeks to:

- act as a vehicle for the dissemination and implementation of appropriate in novative LVSR technology in the SADC region
- promote the use of a holistic approach to LVSR provision
- encourage optimal utilization of local resources and "non-standard", but appropriate, designs for all aspects of LVSR provision
- promote greater local public and private sector involvement and participation in road projects
- ultimately, act as the standard consultative document for LVSRs

Adoption of the above is expected to lead to an increase in sealed roads constructed at an affordable cost and to an appropriate standard by applying proven, sometimes unconventional, methods and innovative technology.

Contrasting examples of low-volume roads in the SADC region

Earth/gravel road (Tanzania).

Old "strip" road (Zimbabwe).

Old "narrow-mat" road (Zimbabwe).

New low-volume sealed road (Botswana).

The Guideline is aimed at a wide range of stakeholders, from politicians to practitioners, including consultants, contractors, materials suppliers, donors, road users and the general public who, in various ways, are all involved in different but complementary aspects of low-volume road provision.

Because the SADC region is a diverse one, it would be impractical and inappropriate to provide recipe solutions for specific situations. Instead, emphasis has been placed on guiding the practitioner towards evaluating alternative options and considering their pros and cons as a basis for decision making and application to country-specific situations. This is achieved by collating together in one document key background knowledge and experience in the application and performance of tried and tested, new and innovative solutions in all aspects of LVSR provision.

The Guideline provides a compendium of recent approaches to the following aspects of low-volume sealed road provision:

- Planning, appraisal and environment.
- Geometric design and road safety.
- Pavement design, materials and surfacing.
- Construction and drainage.
- Maintenance.

The Guideline does not deal in detail with slope stability, geotechnical and hydrological issues or standard drainage details. However, it provides a source of comprehensive references which provide additional details and more fully documented examples of local and international experience.

Although the Guideline has been produced specifically for the SADC environment, there are many aspects of it which, with sound engineering judgement, could apply in similar environments elsewhere.

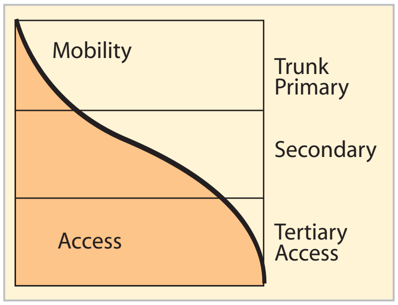
1.3 Focus

The focus of the Guideline is on *Low-volume Sealed Roads* (LVSRs) - a term for which there is no standard definition. Typical criteria for defining such roads include traffic volume, road function, administrative classification as well as management and financing arrangements. The concept of a low-volume road (LVR) also varies from country to country, simply because this type of road serves different functions and operates in different socio-economic environments. In the context of this Guideline, LVSRs are characterized by the following features that pertain to the SADC region:

Table 1.1 - LVSR Characteristics

● **Ownership**	Mostly local governments/communities but also provincial/ central governments.
● **Classification and function**	Mostly secondary or tertiary/access roads but can also be main/ primary roads. Serve predominantly rural populations of most countries – typically more than 75% of the population.
● **Management and financing**	Local government for tertiary/access roads, central government for primary/ secondary roads.
● **Function**	Economic/social/administrative/political.
● **Physical features**	Majority are unsealed, partly engineered, single or 2-lane, earth/sand or gravel roads with elevated running surfaces, side drains and cross-drainage structures, including low or high level water crossings.
● **Traffic**	Relatively "low-volume", *typically* up to about 200 vpd, carrying both motorised and non-motorised traffic.

The multi-functional nature



LVRs are multi-faceted. At one extreme, they serve as a mobility link in the road transport chain from the main highway network to the local market. At another extreme, they serve as an access link in a road transport chain with one end in the agricultural fields or villages and the other in the town market.

Low-volume roads in the region cut across a wide range of environments. In practice, there will be many overlaps in classification and function and clear distinctions will not always be apparent on functional terms alone. Nonetheless, the focus will be secondary/tertiary/access roads in rural and peri-urban areas.

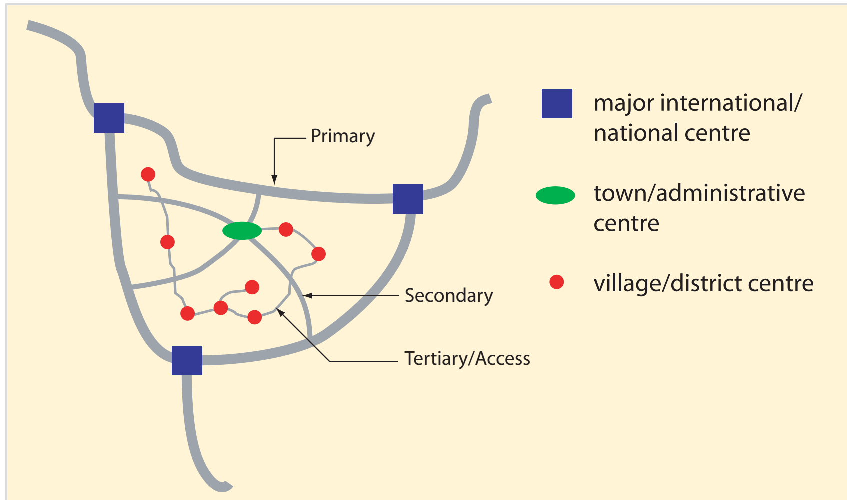


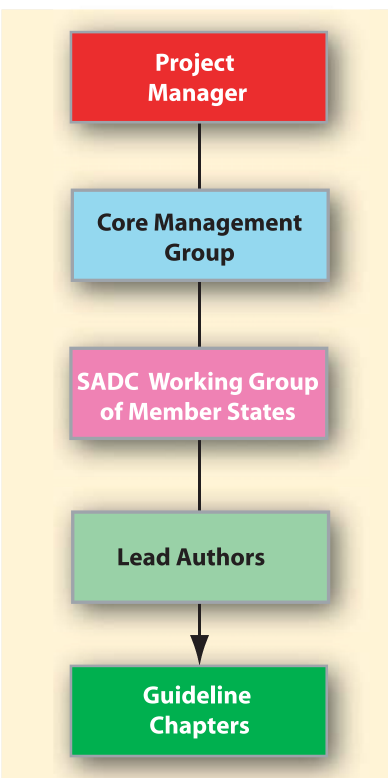
Figure 1.1 - Road hierarchy and function

1.4 Development of Guideline

The Guideline draws on the accumulated knowledge and practical experience of international research organizations, consultants and others who have long experience of working in the region. It was produced by a team comprising key specialists in each technical field, together with experts from SADC countries.

The Guideline is unique in the following important aspects:

1. It was developed with a high level of "local" participation. As a result, it has been possible to capture and incorporate a significant amount of local knowledge in the document. The benefits of this approach include a document that:
   - reflects the needs of the region
   - has an emphasis on local ownership
   - facilitates wider application
   - improves prospects for sustainable implementation
2. It draws extensively on the output of a 4-year SADC regional programme of research in highway engineering materials[2].
3. It focuses on the multi-dimensional nature of LVSR provision, giving balanced attention to aspects of LVR provision that are often neglected in most other guidelines, such as the political, social, institutional and funding aspects.



Organisational chart for management and development of the Guideline.

1.5 Structure and Content

The Guideline is divided into eight chapters which collectively address various aspects of LVSR provision as presented below.

1 Introduction	Comprises the introduction to the Guideline, including an overview of the focus of the document and the approach advocated in contrast to previous approaches to road provision. Against this background, the purpose, scope, development and structure of the Guideline are highlighted.
2 Regional Setting	Provides the geographic setting for the SADC region. Gives an overview of the regional road network and its various details. Highlights the challenge faced in providing LVSRs in a sustainable manner and the developments taking place in road sector reform. Outlines the main components of LVSR provision.
3 Planning, Appraisal and Environmental Issues	Provides a holistic framework for planning and appraising LVSRs and highlights the key external factors that affect their provision. Covers the process of life-cycle costing and the appropriateness of the available appraisal tools for doing so. Presents various environmental issues including the importance of the EIA process in the planning process.
4 Geometric Design and Road Safety	Presents factors relevant to the selection of appropriate standards for LVSRs and the steps involved in selecting suitable solutions. Summarises both conventional techniques and low-cost 'design-by-eye' methods, and the cost, environmental and safety implications of each. Highlights measures for improving road safety on LVSRs.
5 Pavement Design, Materials and Surfacing	Provides a systems approach to the design of LVSR pavements and surfacings derived from regional research work and practice. Highlights the importance of using local materials selected on the basis of appropriate specifications. Emphasises the importance of catering for both internal and external drainage of pavements to enhance performance.
6 Construction and Drainage	Provides guidance on the choice of methods available for the construction of LVSRs, with a focus on labour-based methods. Includes examples aimed at optimising the use of local labour and equipment technologies within a conducive contracting environment aimed at maximizing the use of small-scale local contractors.

7 Maintenance and Road Management

Highlights the importance of maintenance and the challenges faced in carrying it out effectively and efficiently. Presents the particular characteristics of LVSRs, including their deterioration characteristics. Outlines typical maintenance management functions and considers the contractual aspects of undertaking maintenance works. Outlines the role, function and selection criteria for Road Management Systems.

8 From Vision to Practice

Summarises the motivation for producing the Guideline and the benefits of adopting the approaches proposed. Outlines the pathway to implementation of the Guideline, the barriers that need to be overcome in the course of so doing and the need to take account of many non-technical factors that often influence the manner in which LVSRs are provided.

1.6 Updating

As highway engineering technology and improved methods of low-volume road provision are continually being researched and changed, it will be necessary to update the Guideline periodically to reflect improvements in practice.

The Guideline has been produced in a loose-leaf format to allow notes and pages to be inserted as and when necessary. In addition, it has been produced in electronic CD format and has also been posted on the SATCC website www.sadc.int. The Guideline is produced in all three official SADC languages - English, French and Portuguese.

1.7 Sources of Information

In addition to the references cited in the text of each chapter, an extensive bibliography has also been provided for those readers who wish to obtain additional information about any of the topics included. A list of the main organizations producing relevant publications is also provided, including their contact details.

1.8 References and Bibliography

References

1. Transportation Research Board (1979). ***Low-volume Roads: Second International Conference.*** Transportation Research Record 702. National Academy of Sciences, Washington, D.C. August, 1979.

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4. Netterberg F and P Paige-Green (1998). ***Pavement Materials for Low-volume Roads in Southern Africa: A Review.*** Annual Transport Convention, S.443, Vol. 2D, Pretoria. July, 1988.

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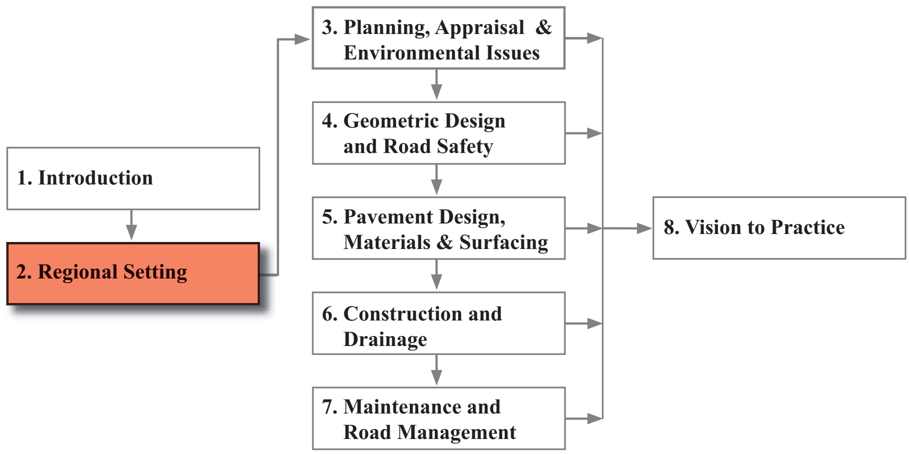
Chapter 2


1. Introduction
2. Regional Setting
3. Planning, Appraisal & Environmental Issues
4. Geometric Design and Road Safety
5. Pavement Design, Materials & Surfacing
6. Construction and Drainage
7. Maintenance and Road Management
8. Vision to Practice

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Regional Setting

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2.1 Introduction

2.1.1 Background

Road transport is essential for the operation of the SADC economy and for the development of national and regional markets. With a total fleet of over 10 million vehicles in 2002, it provides the dominant mode of freight and passenger transport and carries about 80% of the region's total trade in goods and services. It also accounts for about 20% of the region's cross-border trade.

In common with many other developing countries, a large percentage of the population in the SADC region lives in rural areas, where agriculture is the dominant economic activity. In this context, low-volume roads fulfil a critical function in that they generally provide the only form of access to these communities and provide for the mobility of people and movement of goods from the fields to the market place. A good rural road network is therefore essential for improving rural livelihoods and socio-economic growth and development.

Unfortunately, despite the substantial investments made in road transport infrastructure, the cost of road transport services is still inordinately high, especially in rural areas where inadequate transport infrastructure and lack of mobility still impose major constraints on development. There are many reasons for this unsatisfactory situation, some of which are attributable to the questionable nature of various approaches adopted in the provision of LVSRs, many of which have proved to be unsustainable.

Agriculture is the predominant activity in the rural areas of most SADC countries.

2.1.2 Purpose and Scope of Chapter

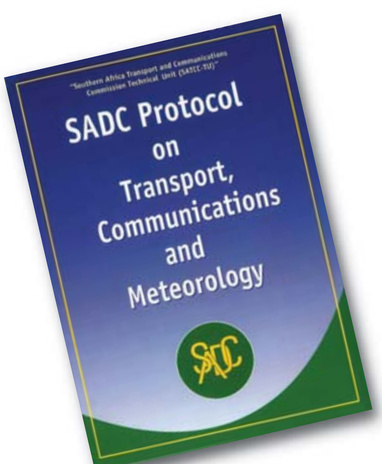
The main purpose of this chapter is to set the background to the SADC region against which the characteristics of the regional road network are presented. Issues relating to the sustainability of the gravel road network and the challenges of alternative approaches for the delivery of low-volume sealed roads are described. A new, more sustainable, multi-dimensional approach is proposed that is set in the context of the reforms taking place in the road sector in the SADC region. These initiatives are designed primarily to improve the management and financing of roads but will also facilitate the implementation of the approaches recommended in this Guideline.

2.2 The SADC Region

The vision of SADC is to transform the fourteen countries of southern Africa from operating as individual fragmented markets into a single integrated vibrant and globally competitive market characterised by free movement of goods, services and labour. Transport, particularly road transport, is an integral component of this vision.

*One of the first institutional priorities identified by SADC was the creation of the **Southern African Transport and Communications Commission (SATCC)** to coordinate the use of existing systems and the planning and financing of additional regional transport facilities. Transport is, therefore, the major initial focus for regional action.*

The bulk of the SADC rural road network is still unsurfaced and in relatively poor condition.



2.2.1 Geographic Setting

The Southern Africa Development Community (SADC) is an economic grouping of fourteen countries located in the Southern African region with a collective land area of about 10 million square kilometers and a population of nearly 200 million people in 2002. Six of the fourteen countries are land-locked and two are island states as shown in Figure 2.1.

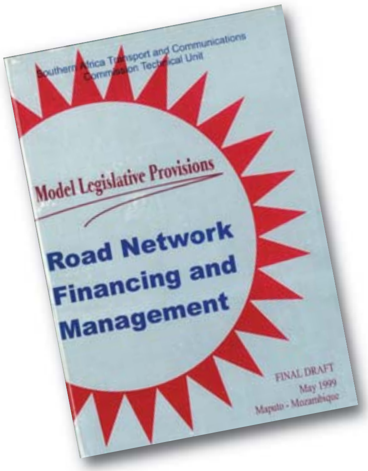
Figure 2.1 - The Southern African Development Community

The SADC region is diverse with climates varying from true deserts through savannah to rainforests. Although the natural resource base is varied, the economies of the various countries are mostly agrarian, with approximately 80% of the population living and working in the rural areas. In such a setting, rural roads play a critical role in support of socio-economic growth and development and, ultimately, poverty alleviation - an over-arching goal of all SADC governments.

2.2.2 Road Sector Reform

Since the late 1990s, the SADC region has experienced a "wind of change" in its approach to road management and financing. It has become increasingly apparent that traditional approaches, which have relied on managing roads through a government department and financing them through general budget allocations, have generally not worked satisfactorily. This has led to the development of the SADC Protocol on Transport, Communications and Meteorology[1].

The SADC Protocol promotes perhaps the most far-reaching set of changes ever contemplated in the roads sector in Sub-Saharan Africa. Its strategic vision is to provide a *"safe, sustainable, efficient and effective road transport system"* in support of regional socio-economic growth and development. Since its ratification by all member states, the SADC Protocol has been implemented to varying extents and with varying degrees of success. All member states are required to fully comply with the requirements of the protocol by 2010.



The restructuring of road management and financing in the SADC region, within a more commercialised institutional framework, is meant to ensure that institutional capacity exists to support improvements in technical capability, such as maintenance operations and management.

Box 2.1 - The main features of the SADC Protocol on Transport, Communications and Meteorology

The SADC Protocol commits member states to the development of a harmonised regional road sector policy with the following main features:

- Clear *demarcating* and *allocating* of authority and responsibilities for *road funding and road management*.
- Establishing *accountable* and *autonomous* roads authorities with public and private sector participation in key decision-making and the ability to source expertise outside civil service restrictions.
- Adopting *commercial management practices* to foster institutional, economic and technical efficiency, amongst others, by introducing competition in undertaking any road-related activity and adopting a preference for the contracting out of all types of road construction and maintenance activities.
- Adopting *appropriate financing principles* and practices to secure adequate and sustainable sources of funding through incremental expansion of road user charging.
- *Dedicating revenues* from roads to their provision, operation and maintenance.
- Identifying *sustainable funding sources* to ensure a regular flow of funds.

SADC Institutional Framework

The agreed SADC institutional framework clearly and unambiguously differentiates between the separate and discrete roles played by key road sector stakeholders in terms of policy formulation, policy delivery and works execution as illustrated in Figure 2.2.

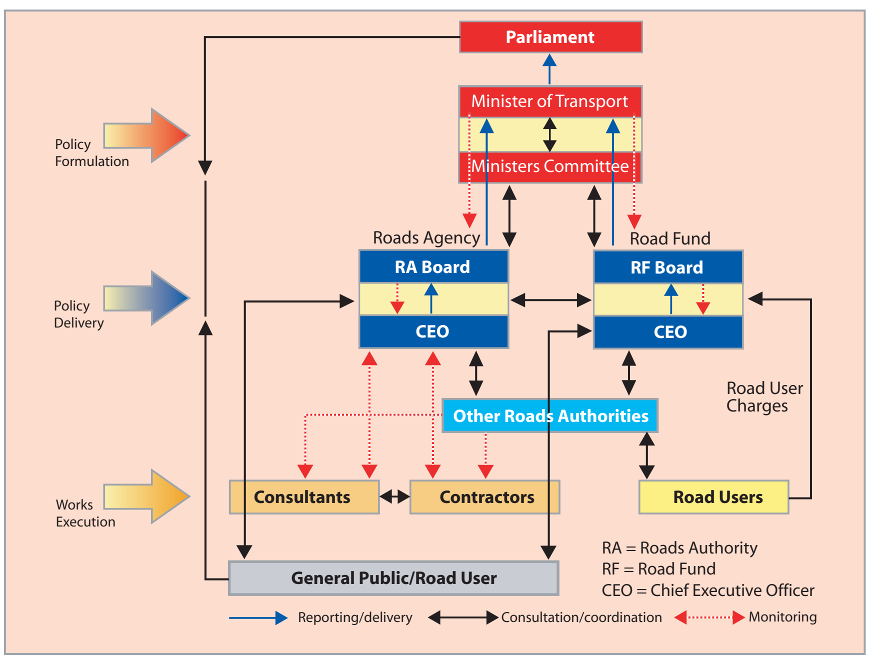


Figure 2.2 - SADC institutional framework for management and financing of roads[2]

Within the new SADC institutional framework, policy, management, financing and operations are treated as follows:

Policy formulation: The overall legal authority for the road network is vested in a *single Ministry* with responsibility for all regulatory, policy, standards and legislative matters. The Ministry has authority over the Transport/ Traffic Agency. The authority over the National Roads Board is limited to approving the level of road user charges recommended by the Board to finance road maintenance and improvement works, and to monitoring the Board's compliance with the terms set out in the legislation under which it was established.

A Ministers' Committee fulfils the function of a policy co-ordination forum in respect of national, regional and local road authorities. The committee also plays an important role in promoting transparency and accountability and democratizing decision-making with regard to roads.

Management: An "arms-length" autonomous or semi-autonomous *Roads Agency* has replaced (or commercialised) the former Roads Department in the Ministry of Transport. Its functions are basically the same as those of the previous Roads Department in terms of strategic management and planning of the development, maintenance and rehabilitation of the national road network, except that they are carried out in a commercial manner. The Agency is overseen by a majority private sector Board and managed on a day-to-day basis by a Chief Executive Officer (CEO).

Financing: An "arms-length" autonomous or semi-autonomous *Road Fund* operates as a commercial agency with responsibility for road financing. In so doing, it:

- acts as a channel for the receipt of all revenues destined for roads
- disburses funds to roads agencies based on simple, transparent procedures
- audits compliance with well defined financial auditing principles

Sustainable funding for road maintenance is based on the *"user pays"* principle and is secured through the levying of a *Road User Charge*. Such a charge reflects the usage of roads and typically consists of a fuel levy on petrol, diesel, vehicle license fees including supplementary heavy vehicle license fees, fines imposed on overloaded vehicles, and any other user charges that may be preseribed by Parliament from time to time.

The funds available from road user charges should not necessarily be spent directly according to traffic level. Low-volume "social" roads will probably need to be subsidised to some extent from the revenues from high-volume "economic" roads.

Operations: All types of road construction and maintenance works should be contracted to the private sector through competitive bidding processes rather than undertaken in-house by Force Account or Direct Labour operations. The procurement of works through performance-specified term contracts and the use of Petty Contractors is increasingly being viewed as the preferred method of contracting out maintenance works, in contrast to the traditional type of contract which, typically, is based on rather prescriptive input specifications and utilises large, foreign contractors.

2.3 Regional Road Network

2.3.1 The Road Network

The total length of the SADC classified road network (Figure 2.3) is just over 930,000 km of which approximately 20 per cent is paved. More than half of the region's total network (511,000 km) is in South Africa. There is also a large network of rural roads in the SADC region, approximately 430,000 km, which consists mainly of 2-lane, all-weather gravel roads and seasonal earth tracks. Most of these roads were constructed in the post independence era of the 1960s and 1970s and are one of the region's biggest assets with current replacement costs in excess of US $50 billion.

The SADC Regional Trunk Road Network (RTRN) comprises approximately 50,000 kms of strategic, intra-regional routes linking capital cities, major regional ports and other areas of economic importance. In addition to the unpaved rural road network, a significant proportion of the RTRN (approximately 30 per cent) also carries relatively low levels of traffic and, hence, these roads are also classified as "low-volume roads".

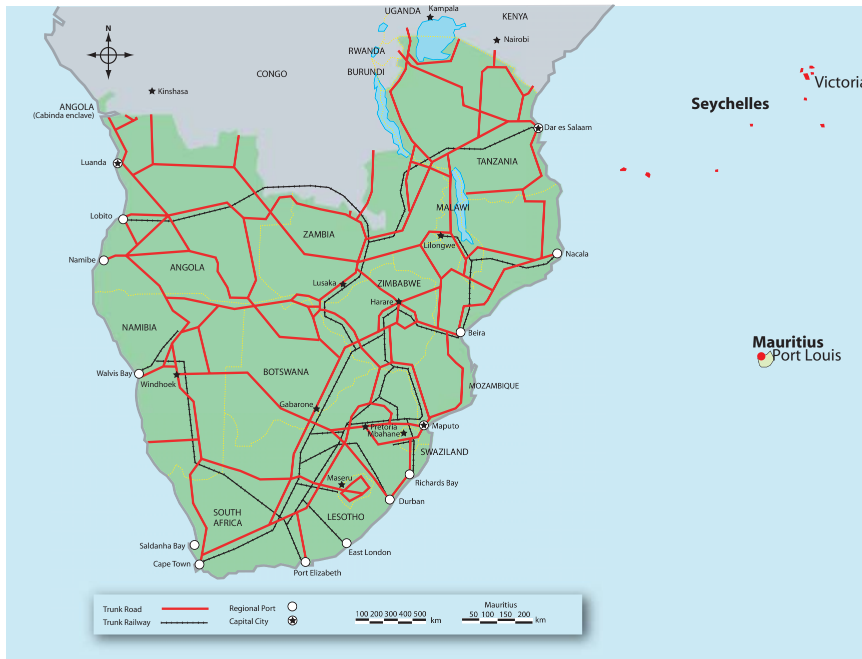
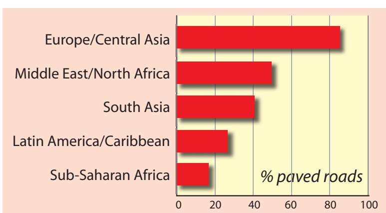


Figure 2.3 - The SADC Regional Trunk Road Network (2001)
(excludes the Democratic Republic of the Congo)



Sub-Saharan Africa, including the SADC region, lags considerably behind Asia and Latin America in terms of road coverage and density[3].

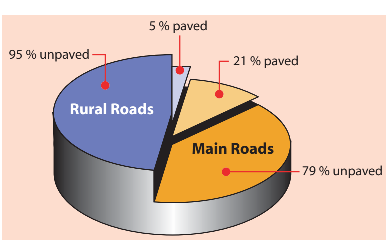
The current main road length averages about 5.6 kilometres for every 100 square kilometers, which is low by comparison with to other developing regions such as Latin America (12 km/100 sq. km) and Asia (18 km/sq. km).

Table 2.1 - Inventory of SADC Regional Road Network

Main Roads			Rural Roads			Total Network		
Paved (km)	Unpaved (km)	Total (km)	Paved (km)	Unpaved (km)	Total (km)	Paved (km)	Unpaved (km)	Total (km)
105,122	395,900	501,022	21,559	409,626	431,185	126,681	805,526	932,207
21.0%	79.0%	100.0%	5.0%	95.0%	100.0%	13.6%	86.4%	100.0%

Source: Report by SAGP consultants; Updates from SADC member states (2001)[4]. (Note: Classification is inconsistent. Main roads can include trunk, regional, main, primary and secondary roads.)

** Excludes the Democratic Republic of the Congo*



A substantial proportion of both the main and rural road networks in the SADC region is unpaved.

2.3.2 Roads and Economic Development

Road transport investment should be viewed as part of an integrated approach considering the economic and social context where improvements take place, and including additional policies on other fronts (e.g. marketing, education, stimulus to demand) that would lead to higher social returns from investment.

The precise role that roads play in economic development is complex but the fact that there is a link is widely accepted and most economists agree that investment in transport infrastructure makes a positive contribution. However, the provision of road transport infrastructure alone is not enough to reap all the possible benefits from interventions. Indeed, recent research[5] highlights two major aspects that should be considered by policy makers: *the access to transport means, and the market organisation for goods and transport services. Thus, SADC governments should also address the need for credit, low-cost vehicles, and intermediate means of transport, and also be prepared to intervene in markets to ensure that benefits become widespread.*

The benefits from road investment vary greatly depending upon the type of interventions, and the social and economic context where they take place. For example, in those rural areas in southern Africa where infrastructure is so basic that vehicle use is difficult or near impossible, facilitating the change to motorised transport would result in major benefits.

In terms of the relationship between km of paved roads/million persons and GDP per capita, the SADC region occupies a relatively low position (Figure 2.4). Thus, improving the efficiency of LVSR provision by providing them at lower and more affordable costs than hitherto, has the *potential* (together with other complementary interventions) for providing considerable benefits to the region's economy and, in so doing, for reducing poverty.

Road network density in developed countries is generally much higher than in developing countries. However, the cost of building roads is not proportional to the wealth of a nation in terms, for example, of the GDP per inhabitant. Thus, with the GDP per inhabitant being 10 to 20 times lower in developing countries, the cost of road provision is two to three times higher than in developed countries. It is therefore critically important that paved road construction costs are minimized through the selection of appropriate standards and implementation strategies.

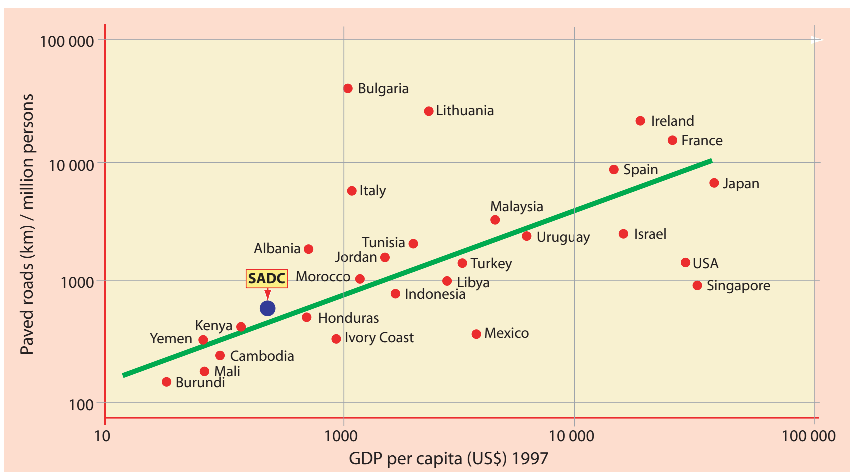
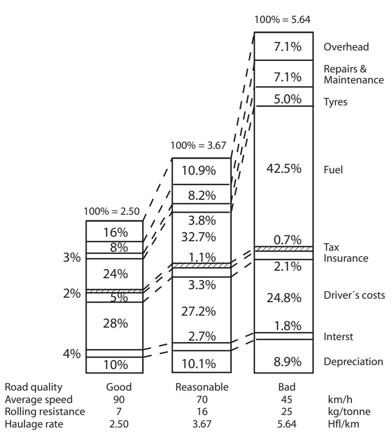


Figure 2.4 - International comparison of paved road density and GDP per capita

Pedestrians and non-motorised traffic often constitute a significant proportion of traffic near villages.



Source: PIARC (1987)

The influence of road conditions on haulage costs - both the operating and maintenance costs of vehicles escalate with increasing rapidity as the surface condition worsens (PIARC, 1987).

2.4 Road Network Details

2.4.1 Classification and Traffic Flows

Roads in the SADC region are typically classified according to function as shown in Table 2.2 and illustrated in Figure 1.1.

Table 2.2 - Typical road functions and classification

Road Function				Design Class	Traffic Flow (AADT)	Typical Surface Type
Tr	P	S	Te			
■ (grey)	■ (black)			A	> 2000	Paved
	■ (black)			B	500 - 2000	Paved
	■ (black)	■ (green)		C	200 - 500	Paved/Unpaved
		■ (green)	■ (red)	D	50 - 200	Unpaved
			■ (red)	E	< 50	Unpaved

Key Tr = Trunk P = Primary S = Secondary Te =Tertiary/access

With the exception of South Africa, and apart from a few heavily trafficked international routes, most of the main roads carry modest volumes of traffic, with little more than about 10 per cent carrying over 2000 vpd, approximately 25 per cent of which consists of heavy, often over-loaded, commercial vehicles. On rural roads, traffic volumes are relatively very low and much of this network carries traffic in the range of 50 - 200 vpd. Near village centres non-motorised traffic, including bicycles, often comprises a significant proportion of the total traffic.

The "low-traffic" characteristics of much of the rural road networks in the SADC region have implications for geometric design, pavement and drainage structures, road furniture and maintenance practice and, indeed, the manner in which investment appraisals are carried out.

2.4.2 Design Standards

Road design standards in the SADC region vary considerably, reflecting either the practice of the developed countries with which member states have had previous ties, or the preferences of international consultants, usually donor funded, who have worked in the country. Thus, British, American, Portuguese, French, German and other standards have left their mark on the road infrastructure. In many instances, these standards have been inappropriate for cost-effective application in the SADC region where the physiographic, socio-economic and environmental conditions vary tremendously from those prevailing in the countries of origin of the standards.

2.4.3 Road Conditions

About 50% of the paved main road network is currently (2001) in good condition, with the remainder classified as only fair or poor, as shown in Table 2.3. The unpaved main road network is considerably worse than the paved road network, with less than 40% being in good condition. The net result is that transport costs are very high with estimates of four to five times of those in developed countries and, for some landlocked countries, as high as 30 - 40 per cent of the price of goods[6].

Can any country afford roads in this condition?

"My country was never so rich that it could afford poor roads"

(William the Conqueror, Doomsday Survey, 1066).

Table 2.3 - Condition of main roads in the SADC region

Main Roads	Road Condition (Weighted Average)		
	Good	Fair	Poor
Paved	49	36	15
Unpaved	38	31	31

Sources: Report by SAGP consultants to SATCC[4]; Updates from member states (2001).

Notes:

Good: Substantially free of defects and requiring only routine maintenance. Unpaved roads need only routine grading and spot repairs.

Fair: Having significant defects and requiring resurfacing or strengthening. Unpaved roads need reshaping or re-gravelling and spot repair of drainage.

Poor: Having extensive defects and requiring immediate rehabilitation or reconstruction. Unpaved roads need reconstruction and major drainage works.

Rural poverty in the SADC region is exacerbated by the prevailing poor road conditions which adversely affect accessibility and, as a result, limit the facilitating role of transport in both production and consumption activities. Improvements in the quality and reliability of the rural road network are therefore critical for development and poverty eradication, the over-arching goal of all SADC governments.

For these reasons, most of the current investment in the roads sub-sector involves upgrading these predominantly low-volume, rural secondary and feeder roads to an improved standard at minimum life-cycle cost - which is the main focus of this Guideline.

The high accident rate in the SADC region is a source of loss and damage to trade and one of the major causes of injury and death.

2.4.4 Road Safety

There is a serious road safety problem in all countries of the SADC region. This is characterised by a high rate of road accidents involving pedestrians and other vulnerable road users, particularly on rural roads where vehicle speeds tend to be relatively high. Fatality rates, in relation to vehicle fleets, are estimated to be 30 - 40 times higher than those of industrialised countries and cost the region between one and three per cent of its annual GDP[7].

Fortunately, there is now a widespread recognition that much more can be done to improve the poor road safety situation. This includes improvements in road design and the more widespread use of road safety audits. These issues, amongst others, are dealt with in Chapter 4 of the Guideline.

2.5 Low-volume Sealed Roads

2.5.1 The Challenge

In the past, geometric design standards were not specifically addressed in the SADC region. Both road planners and designers were faced with either using "national" imported standards that were developed for a higher classification of roads or reducing these higher classification standards to meet economic constraints, usually without a logical basis for doing so.

A number of factors combine to pose a major challenge to road authorities in the provision of LVSRs. In this regard:

- They generally constitute a high proportion (typically 80%) of the road network for which available resources are severely limited.
- Limited funding tends to be allocated in favour of HVRs which are perceived as fulfilling an important economic role even though LVRs fulfill at least equally important social and development functions.
- Social and developmental benefits are often dealt with inadequately in traditional investment appraisal methodology.
- There has been a tendency to focus predominantly on the technical aspects of LVSRs, with inadequate attention being paid to the other environments within which they operate and which influence their long-term sustainability.
- Traditional highway engineering, planning and standards that are applied to roads with higher volumes of traffic are often not appropriate for LVSRs and, when used, result in unnecessarily expensive solutions.
- Although traffic volumes may be relatively low, vehicle loads are often high, with significant overloading. This makes the relatively light pavement structures, that would otherwise be appropriate, vulnerable to overloading.
- The allocation of limited research funding tends to be prioritized in favour of high-volume roads which are perceived to offer higher rates of return.

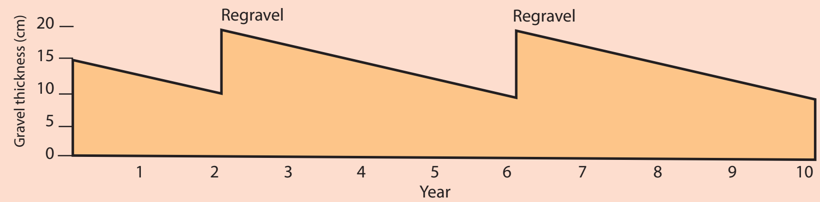
In addition to the challenges faced by road agencies in providing LVSRs, transport agencies also face a major challenge of providing affordable transport services to rural communities. However, although closely related, this topic is outside the scope of this Guideline.

2.5.2 Gravel Road Issues

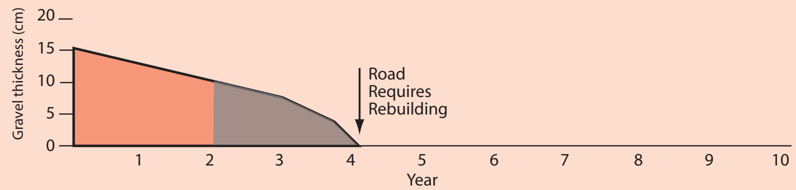
Based on a typical regravelling cycle of 3 - 4 years and a replacement gravel thickness of 100 mm over a 6.5 m carriageway, the annual consumption of gravel in the region is of the order of 150 million cubic metres. Is this process sustainable in the medium to long term? ***NO!***

A substantial proportion of the rural road networks, and to a lesser extent, of the main road networks in the SADC region, are currently unpaved. These roads need to be continuously regravelled utilizing naturally occurring gravels, a finite, often scarce, non-renewable resource.

In practice, many countries do not have the necessary financial resources to sustain their gravel road networks. As illustrated in Figure 2.5, this quickly leads to the total loss of the investment as well as to all-weather access for the communities that these roads serve.



(a) Gravel thickness with preventative maintenance (timely regravelling).



(b) Gravel thickness without preventative maintenance (no timely re-gravelling).

Figure 2.5 - Periodic maintenance (regravelling) of unsurfaced roads[10]

Due to loss of fines, gravel roads often become very rough which make driving conditions hazardous and, in addition to severe driver discomfort, impose very high vehicle operating costs.

Generation of dust is a constant hazard to over-taking motorists as well as to inhabitants living nearby and their crops.

Sustainability considerations

There are a number of very serious concerns to national governments, development agencies and rural communities regarding the use of gravel road surfaces. These are summarized in Table 2.4.

Table 2.4 - Gravel road sustainability considerations

Issue	Sustainability Factor
• **Financial and economic**	❍ Gravel is a sacrificial layer and replacement is at a high cost: - 30 to 150 mm can be lost per annum - regravelling operations cost US $5,000 to 30,000 per/km/year - periodic maintenance costs US $2,000 to $3,000/km/year - continuous regravelling is a significant recurrent financial burden
• **Institutional and management**	❍ Unpaved roads: - typically constitute 70 to 90% of the main road network and most of the undesignated network - generate a continuous cycle of deterioration and backlog maintenance ❍ Roads agencies: - suffer logistical, technical and financial constraints - often have limited physical, human and natural resources - have little capacity to intervene in maintenance activities as required
• **Standards and technology**	❍ Wastage of finite resources (selective gravelling difficult in practice). ❍ Expensive mechanised approaches required for regravelling result in: - operational, support and technical problems - local financing burden ❍ Potential longer term sustainability of labour-based methods
• **Social**	❍ Land take and rehabilitation of borrow pits.Wet weather access problems for communities continue. ❍ Generation of dust in dry weather with adverse impacts including: - health hazard - pedestrian and vehicle safety - crop, natural habitat and vehicle damage
• **Environmental**	❍ Continuous demand for use of non-renewable natural resources which are being seriously depleted. ❍ Haul distances and costs continually increase. ❍ Land take continues. ❍ Roads susceptible to erosion (silting of drains and water courses). ❍ Chemical treatment options can be hazardous.

For the above reasons, it is now abundantly clear that the time has come to provide more sustainable solutions to low-volume roads in many SADC countries by sealing them, where viable, at an affordable cost. Meeting this challenge is the main focus of this Guideline.

2.5.3 Need for Sustainable Strategies

Traditional approaches to LVSR provision have tended to focus somewhat narrowly on the technical environment with inadequate consideration of the other inter-related environments shown in Figure 2.6. The result has often been a lack of responsiveness to the needs of various stakeholders and a reduced likelihood of achieving sustainable solutions[8,9].

Lessons learned from the region indicate that if LVSRs are to be provided in a more sustainable manner than hitherto, new approaches are required that focus in a more holistic way on a number of factors operating within multi-dimensional, inter-acting environments.

By their nature, LVSRs fulfil a variety of economic and social functions and their provision is influenced by a number of complex, inter-acting environments in which non-technical factors play a crucial role. Thus, it is of paramount importance that emphasis is placed on a multi-disciplinary, participatory approach in the planning, design, construction, maintenance, etc., of LVSRs.

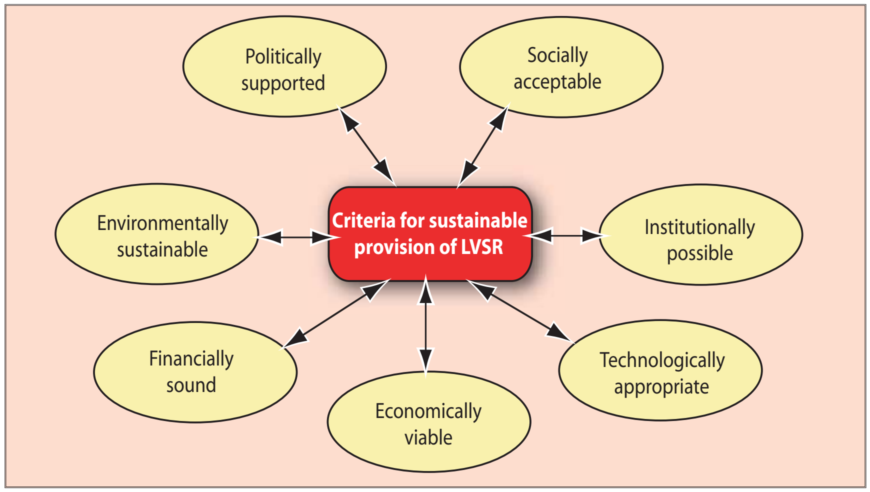


Figure 2.6 - A new framework for sustainable provision of LVSRs

Achieving sustainability in the provision of LVSRs requires an important shift of emphasis from a relatively narrow focus to a more broadly focused, multi-dimensional approach in which a number of influential factors need to be considered as indicated in Table 2.5.

Table 2.5 - Factors affecting the provision of LVSRs in the SADC region

Environment	Sustainability factors
• Political	***Government policy:*** *Often no coherent policy in place.* • Need to highlight the key benefits to be derived from LVSRs leading to the development of a comprehensive policy that: ❍ promotes sustainability in all aspects of LVSR provision ❍ covers wider social and economic goals of poverty alleviationan by implication, employment creation ❍ promotes the use of appropriate technology as well as environmental awareness ***Political and public perceptions:*** *Tendency to favour conventional approaches and standards with perceived minimum "risk" attached to them.* • Need to maintain continuous dialogue with political and public stakeholders in order to: ❍ highlight pros and cons of alternative solutions in a balanced and transparent manner ❍ more determinedly "sell" proven innovative approaches and appropriate, non-traditional standards on the basis of quantified benefits

• **Social**	***Social issues:*** *Tend to be neglected or to be subordinate to technical and economic issues.* • Adopt strategies that: ❍ support cost-effective labour-based methods of construction and maintenance ❍ ensure community participation in mainstream policy, planning and decision making ❍ eliminate gender biases and promote participation by women in labour-based activities ❍ promote activities and investment for sustainable enhanced livelihoods ❍ minimise the amount of resettlement and, where unavoidable, mitigate its effects by expeditious and compensated resettlement
• **Institutional**	***Institutional capacity:*** *Often inadequate. Growing trend towards establishment of more autonomous central and local road authorities.* • Adopt strategies that: ❍ promote commercial management practices to foster institutional, economic and technical efficiency in the provision of LVSRs ❍ reduce and eventually phase out in-house, force account operations in favour of contracting out of works to the private sector ❍ define and develop an optimal environment for the development of local contractors
• **Technical**	***Technology choice:*** *A wide range of options is available for designing, constructing and maintaining LVSRs.* • Adopt strategies that: ❍ employ appropriate design standards and specifications ❍ utilise technologies that create employment ❍ use types of contract that support the use of local contractors ❍ promote road safety in all aspects of LVSR provision
• **Economic**	***Economic analysis:*** *Traditional approaches are often unable to capture the full benefits of LVSR provision.* • Adopt strategies that: ❍ integrate social, environmental and economic elements in project appraisal ❍ use appropriate evaluation tools capable of quantifying social, economic and environmental costs and benefits
• **Financial**	***Funding:*** *Usually inadequate to meet minimum requirements.* • Adopt strategies that: ❍ promote commercialisation in the roads sector ❍ establish sustainable sources of funding
• **Enviromental**	***Environment:*** *Generally regarded as the price to be paid for development and often neglected.* • Adopt strategies that: ❍ minimise the physical impacts of construction and maintenance ❍ take account of socio-cultural impacts (community cohesion) ❍ resource management (recycling of non-renewable materials) ❍ recognise that climate change should be taken into account in the design process

2.5.4 Main Components of LVSR Provision

The four major components of LVSR provision that will typically be undertaken within the new SADC institutional framework are as follows:

- Planning
- Design
- Construction
- Maintenance

These components have important but changing impacts on the end result - a *Low-volume Sealed Road* - in terms of their "level of influence"[11]. Figure 2.7 illustrates the essential features of the "level of influence" concept in terms of how the effect on the total life-cycle costs of a LVSR project decreases as the project evolves.

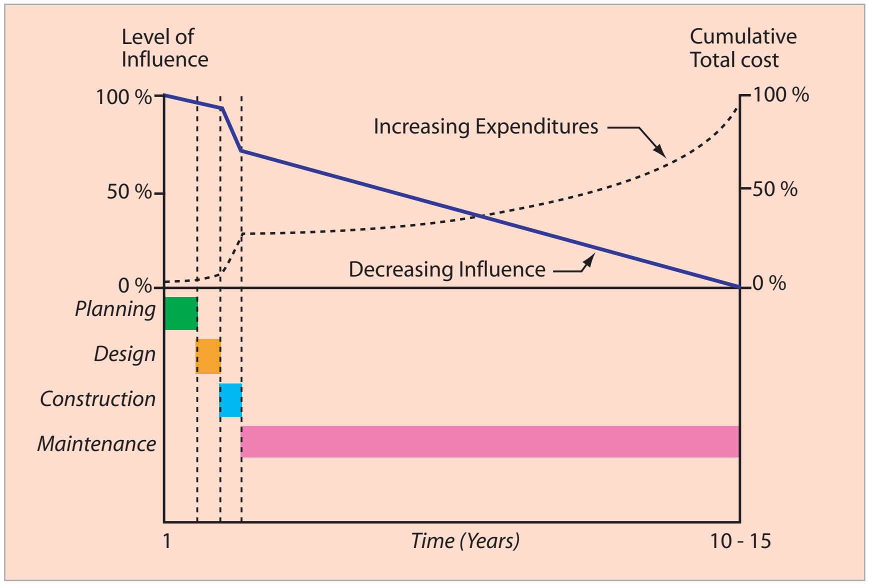


Figure 2.7 - Influence level of LVSR components on total costs

In essence:

- Costs during the planning and design phases are relatively small compared with the total expenditure and are incurred during a relatively short period of the project's life. However, their downstream level of influence is very large in terms of decisions and commitments made during the early phases of the project.

  This emphasizes the importance of employing a broadly-based, holistic approach to the planning of LVSRs with the main stakeholders being involved in the decision-making process. In addition, the designs employed (geometric and pavement) should be appropriate and relevant to the environment in which the road is being constructed.

- The capital costs for construction are a fraction of the operating and maintenance costs associated with a pavement life-cycle. However, the decisions made during the construction phase, and the methods of construction adopted, can have a great impact on the cost of maintaining the road.

  This emphasizes the importance of ensuring a high degree of quality control in the use of local materials and the adoption of construction methods that are appropriate to the multi-dimensional environment in which the road is being provided.

- Maintenance occupies a significant number of years in the life of the project and the type and cost of maintenance required is influenced significantly by the preceding planning, design and construction phases.

  This emphasizes the importance of ensuring that the maintenance phase is prolonged as much as possible to extend the useful life of the road and the period of time during which benefits are incurred.

- At the beginning of the project, the roads agency controls all factors (100 per cent influence) in determining future expenditures. The key issue is how to optimize the use of scarce resources in the provision of LVSRs in an efficient, effective, appropriate and sustainable manner.

The subsequent chapters of the Guideline deal in turn with the main components of LVSR provision - planning, design, construction and maintenance - with particular emphasis on the "level of influence" concept described above.

2.6 Summary

The key points raised in this chapter are:

1. Roads are central to economic development and poverty alleviation as well as to creating opportunities for employment in the SADC region. Despite the substantial investments made in road infrastructure, road transport costs remain very high, particularly in rural areas, and this has had an adverse impact on the regional economy.

2. The road network of about one million kilometres is characterised by relatively low traffic levels (< 200 vpd) outside of urban areas, variable design standards, poor road conditions and a very serious road safety problem.

3. More than 80% of the regional road network is unpaved. In the medium to long term, continuous gravelling or regravelling of these roads is unsustainable. Consideration must be given to sealing them, where viable, at an affordable cost.

4. New, more sustainable, broadly focused, multi-dimensional approaches are required to deal effectively and efficiently with the management of the large kilometrage of unsurfaced roads.

5. The region has embarked on major reforms of the road sector with the objective of managing and financing roads within a more commercialised environment. This will have a profound effect on the way in which the sector operates in future and provides the potential for substantial improvements in the provision of LVSRs.

6. The main components of LVSR provision - planning, design, construction and maintenance - have important but changing impacts on the end result in terms of their “level of influence”.

This chapter puts into context the challenges that road agencies in the region face in providing LVSRs in a sustainable manner - challenges that are addressed in subsequent chapters of the Guideline.

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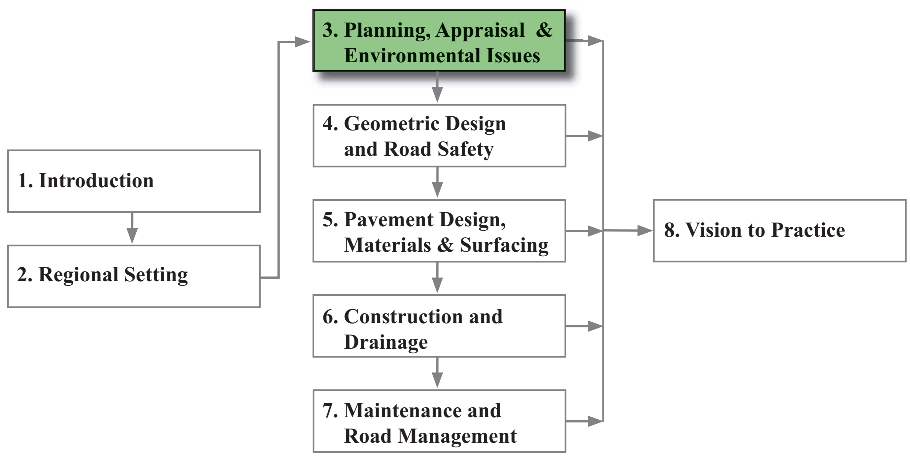
Chapter 3



3. Planning, Appraisal & Environmental Issues
4. Geometric Design and Road Safety
1. Introduction
5. Pavement Design, Materials & Surfacing
8. Vision to Practice
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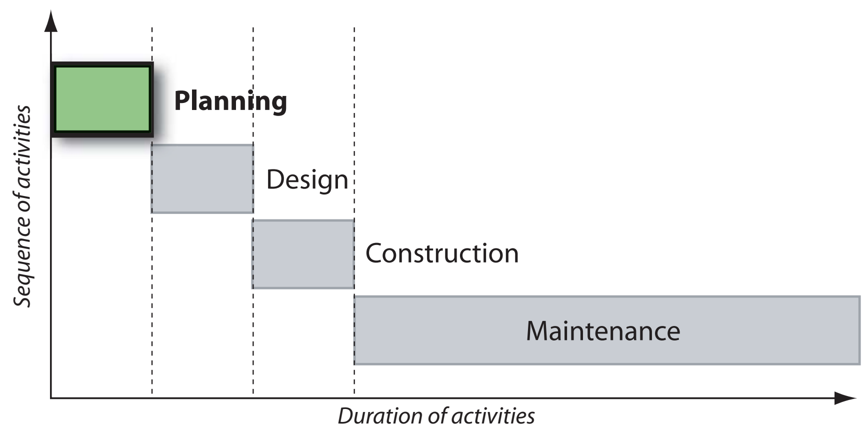
Planning, Appraisal & Environmental Issues

3

3.1 Introduction

3.1.1 Background



As indicated in Chapter 2, planning exerts a substantial level of influence on the downstream aspects of LVSR provision in terms of its impact on the subsequent design, construction and maintenance phases. The planning phase can therefore be rightly viewed as the foundation on which the subsequent phases are based. It is an activity aimed at considering a wide range of options with the objective of providing an optimal, sustainable solution, i.e. one which satisfies the multiple needs of stakeholders at minimum life-cycle costs.

It is noteworthy that planning technologies and techniques that are often applied in the region generally draw little distinction between low-volume and high-volume roads even though these roads have quite different characteristics. As a result, many aspects of LVSR sustainability are not adequately addressed. Failure to revise or adapt these planning approaches to cater specifically for low-volume roads can lead to the adoption and implementation of sub-optimal solutions that are unsustainable.

The appraisal of LVSRs also requires careful consideration. This is largely because the traditional tools that are available for their evaluation are generally not adequate for capturing the full range of benefits - often of a predominantly social rather than economic nature - that arise from their upgrading. This indicates the necessity for adopting methods of appraisal that include more socially oriented investment criteria so as to accord with the social objectives of poverty alleviation. Fortunately, new, customised economic evaluation models are being developed which are better suited than hitherto for appraising the upgrading of unpaved roads to a bituminous standard.

Prior to the start of the 1990's, environmental impact assessments of road projects were generally not required and, where carried out, were done largely at the insistence of donors. However, environmental issues are now assuming greater importance than hitherto and environmental degradation is no longer being regarded as the price to be paid for development. More and more environmental units are being established within parent ministries to ensure that appropriate mitigation measures are employed on road projects. This requires an integrated framework for dealing with environmental issues in a comprehensive and systematic manner.

3.1.2 Purpose and Scope of the Chapter

The main purpose of this chapter is to outline a generalised approach to planning which is holistic in nature, taking into account the many external factors that affect the process. The chapter also highlights approaches that are typically adopted in the appraisal of LVSRs and provides guidance on their adequacy for dealing with the full range of benefits arising from upgrading earth/gravel roads to a sealed standard. Finally, the chapter considers the environmental issues facing road authorities in the region and the various methods available for mitigating the adverse impacts of road construction and maintenance.

3.2 Planning

3.2.1 General Approach

A road where one or more of the seven dimensions of sustainability is missing.

Current approaches to the planning of LVSRs place greater emphasis than hitherto on the important issue of *sustainability*. Achieving sustainability in the provision of roads continues to elude transport professionals in many countries. There are still many examples of roads being constructed which, because of lack of sustainability in one way or another, often as a result of inadequate maintenance, have resulted in wasted investments.

As highlighted in Chapter 2, a holistic approach is required in which all dimensions of sustainability are addressed at the planning stage. This places more weight on multi-disciplinary planning in which teams consisting of planners, engineers, environmentalists, etc. work together with stakeholders in order to reach optimal solutions in the most cost-effective way. Such an approach provides the best chance of achieving long-term sustainability of projects and is strongly promoted in this Guideline.

Planning for labour-based construction and maintenance works has also taken on a new emphasis as more and more SADC governments recognise the benefits of adopting this approach, where viable, as a means of providing much needed employment.

3.2.2 Planning Framework

A major challenge faced by planners and engineers in the SADC region is to ensure that the planning and appraisal procedures produce outputs that have the full support of decision makers. Such a framework should be transparent, relatively simple to carry out, unambiguous and equitable. Table 3.1 presents a generalised framework for this purpose.

When needs are great and resources limited, selection methods are necessary to make sure that only the roads with the greatest impact are constructed. Such methods should not be too costly to apply in proportion to the investment involved, nor should they be so complicated that few understand how they work. Ideally, selection methods should ensure that few good candidate projects will be rejected and not too many poor ones accepted.

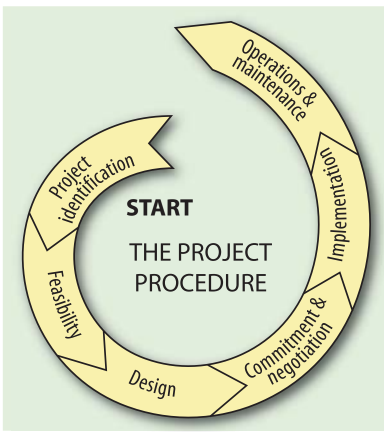
Table 3.1 - Framework for planning and appraisal

Project Cycle	Planning Activity	Typical Evaluation Tools	Output
Identification	Selection	Policy resource analysis Master Plans Local/regional plans	Long list of projects
Feasibility	Screening	Livelihoods analysis Integrated Rural Accessibility Planning	Shorter list of projects
Design	Evaluation	Cost-benefit analysis - consumer surplus (e.g. RED) - producer surplus - compound ranking - multi-criteria analysis	Short list of projects
Commitment and negotiation	Prioritisation	Budget considerations - ranking by economic or socio-economic criteria	Final list of projects

In principle, the planning and appraisal processes are structured activities which start from the general and work towards the particular in relation to both data and project ideas[1]. The main features of the planning and appraisal processes are as follows:

Proper selection and screening of candidate road projects at an early stage of the planning process are important.

Typical Project Cycle



It is important that both the client and the contractor share a common vision on the standard of the road to be constructed.

Box 3.1 - Planning and appraisal processes

- **Selection:** This is a multi-sectoral and multi-disciplinary process which should generate sufficient projects to ensure that no potentially worthwhile ones are excluded from consideration. The output is a long list of projects determined on the basis of an *unconstrained policy resource analysis* that satisfy national road transport policy.
- **Screening:** Defines the constraints within which specific planning solutions must be found, i.e. a *constrained policy resource analysis*. The output is a shorter list of projects that justify further, more detailed, analysis.
- **Evaluation:** The shorter list of projects is subjected to a detailed cost-benefit appraisal for which various methods are available. The output is a final list of projects which satisfy a range of criteria - political, social, economic, environmental - at least cost.
- **Prioritisation:** Ranks the "best" projects in order of merit up to a cut-off point dictated by the budget available.

3.2.3 Planning Considerations

The procedures described in the planning and appraisal framework shown in Table 3.2 are common to any type of road project. However, there are aspects of it that are of particular significance in the planning and appraisal of LVSRs that often do not emerge from conventional approaches. These are summarised below:

Table 3.2 - Project cycle and related activities

Stage	Issues to be considered
Project identification • Project objectives	• Are the strategies being adopted supportive of government policy? (e.g. employment creation). • Are they relevant to the current and future needs of beneficiaries? • Are they cognisant of the multiple objectives and views of stakeholders? • Have effective communication channels with stakeholders been created? Are they gender sensitive?
Feasibility • Design criteria • Cost-benefit analysis • Socio-economic assessment • Road safety assessment • Environmental assessment • Livelihoods	• Is there adequate participatory planning and consultation with public and private sector stakeholders? • Do the design criteria take full account of the specificities of LVSRs, including non-motorised traffic? • Are appropriate evaluation tools being used? • Has a base line environmental survey been undertaken? • Has a road safety audit been incorporated in the project?
Design • Design standards • Pavement/surfacing design	• Are the geometric, pavement design and surfacing standards technically appropriate? • Are they environmentally sound? • Are specifications and test methods appropriate to local materials being used?
Commitment & negotiation • Contract documentation	• Do designs accommodate construction by labour-based methods? • Do they include environmental protection measures? • Have tender documents been prepared and contract strategies adopted that facilitate involvement of small contractors?

The end result - a successfully completed project that meets the requirements of all stakeholders by satisfying the seven key dimensions of sustainability.

Implementation ● Construction ● Inspection and monitoring ● Environmental mitigation	● Have labour-based rather than equipment-based methods of construction been adopted where feasible? ● Are environmental mitigation measures contained in the contracts? Are they enforcable? ● Have specific measures been included in the contract to cater for health and safety matters such as HIV/AIDS?
Operations and maintenance ● Performance evaluation ● Maintenance operations	● Have the various indicators of socio-economic well-being been monitored and evaluated? ● Are there adequate arrangements for community participation in road maintenance? ● What are the lessons for the future?

Thus, in the planning and appraisal of LVSRs, it is necessary to consider carefully the multi-dimensional range of issues highlighted in Table 3.2 that can significantly influence the output of the process.

Labour-based construction: *The economically efficient employment of as much labour as is technically feasible to produce as high a standard of construction as demanded by the specification and allowed by the funding available. This implies an optimal balance between labour and equipment.*

Labour-intensive construction: *The use of as much labour as possible by substituting men for machines often to satisfy short-term needs. This implies an imbalance between labour and equipment and, invariably, an economically inefficient end product.*

Labour-Based Projects

In view of the emergence of labour-based approaches as a viable alternative to some aspects of the more traditional plant-based approaches, the planning of such projects merits special consideration. Without appropriate technical and financial planning from the inception of a project, serious problems may ensue, which may ruin the initiative and bring into disrepute the practicability and objectives of labour-based projects.

Many items need to be investigated in terms of their suitability for labour-based methods of construction or maintenance. Contractual aspects need to be established and appropriate designs undertaken. Such planning must extend beyond engineering technology and the practicality of construction and also consider such factors as the financing and management of labour-based projects. Guidance and training on such issues is provided by a number of international organisations in the SADC region, including the International Labour Organisation Advisory Support, Information Services and Training (ILO/ ASIST).

"We know that employment is the first step towards escaping from poverty".

Juan Somavia, Director General of the International Labour Organisation (ILO), 2001.

Box 3.2 - Why labour-based construction?

The primary objective of labour-based projects is to complete construction efficiently and economically within a specified time. Secondary objectives include:

- Employment creation.
- Creation of local entrepreneurs.
- Optimization of the use of local resources.
- Creation of skills.
- Improvement of labour productivity.
- Construction of a technically sound, economically efficient product.

For many people, labour-based work may be their first formal job and a future doorway to other forms of work. Moreover, money which would go out of the community is retained and the skills attained can be applied later in the maintenance of the project throughout its life, or on other similar projects.

3.2.4 External Factors

There are a number of external factors, many of them of a non-technical nature, that directly or indirectly affect the planning process itself or the outcomes from that process. It is important to be aware of them when devising an appropriate planning procedure and, where possible, to take them into account. These various factors are listed in Table 3.3.

Decision making should be based on rational technical, economic or social factors which, ultimately, should be coincident with the best political options. However, frequently, the political factors take precedence over technical, economic or social factors.

Table 3.3 - External factors that affect the planning of LVSRs

Environment	Factor	Implications on approach to LVSR provision
Political	• Government policy • Political perceptions • Political involvement	• Influences practice. Covers issues such as poverty alleviation, sustainable socio-economic development, technology choice, employment creation, standards, sources of funding. • Tendency to favour conventional approaches and standards with perceived minimum "risk" attached to them. There is a need to communicate effectively, quantify and "sell" innovative approaches and appropriate, non-traditional standards. • To be expected. Will tend to influence decision-making. Highlight pros and cons of alternative solutions in a balanced, transparent manner and maintain continuous dialogue with stakeholders.
Social	• Poverty alleviation • Sustainable livelihood • Gender considerations	• Implies use of labour-based rather than fully plant-based methods, where feasible. • Enhance local participation and resource mobilisation by involving the people who will ultimately benefit from the projects. • Understanding community strengths and weaknesses, assets, vulnerability to shocks and constraints, governance issues and policies needed. • Eliminate gender biases by integrating the transport needs of women in the mainstream of policy and planning. • Promote participation by women in labour-based construction and maintenance programmes and training to assume supervisory roles.
Institutional	• Organisation	• Growing trend towards establishment of more autonomous central and local roads authorities. • Greater scope for generating accountability for results in road programmes and moving from force account to contracting out of work to the private sector.
Technological	• Technology choice	• Need for cost-effective strategies that utilise the dual output of road infrastructure and employment creation.
Economic	• Evaluation	• Road benefits are often not limited to use of road, but alsofrom the way in which the road is financed, designed, constructed and maintained. There is a need to capture monetary and non-monetary benefits in the evaluation ramework.
Financial	• Funding • Sustainability	• Usually very scarce. Financing proposals must look increasingly at minimum standards, limited donor funding and local funding of recurrent maintenance costs. • Sustainability of funding has become a critical issue. There is a need to commercialise operations where possible and involve stakeholders in the maintenance of facilities.
Environmental	• Impact	• Need to capture social as well as environmental impacts in the evaluation of LVSRs. • Address health-threatening impacts as a high priority.

3.2.5 Planning Tools

Policy Analysis

The objective of policy analysis is to define, in general terms, the constraints within which specific planning solutions must be found. Constraints may relate to such factors as government policy on employment, provision of accessibility, income distribution and regional development as well as technical factors such as type of terrain and transport facilities, level of existing traffic, capacity and expertise of the local construction industry, availability of finance, etc.

"A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and which contributes net benefits to other livelihoods at the local and global levels and in the long and short term."

Chambers and Conway, 1992[2].

Master Plans

Master plans or regional plans are used in many SADC countries to help in determining priorities for the future. These plans are not transport specific but relate to all sectors and help to identify investment requirements and priorities over a defined period. It is at this stage that new road projects will first be identified.

During the preparation of a master plan it is important that transport planners liaise closely with other Ministries. In the rural context particular priorities will include education, health and agriculture. It is also important that extensive consultation is undertaken with local communities and opinion leaders.

Livelihoods Framework

"Livelihoods Analysis" is a useful approach to adopt in order to identify the ways in which any particular investment intervention will impact, benefit or disadvantage the local community[2]. A rural livelihoods analysis provides a framework for understanding how any proposed changes will affect personal or community livelihoods in the longer term. It focuses directly on how the local community uses and develops its social (S), human (H), financial (F), natural (N) and physical (P) asset structure (see Figure 3.1).

H = human capital: the skills, knowledge, ability to work and good health are important to the ability to pursue different livelihood strategies.

P = physical capital: the basic infrastructure (transport, shelter, water, energy and communications) and the production equipment and means that enable people to pursue livelihoods.

S = social capital: the social resources (networks, membership of groups, relationships of trust, access to wider institutions of society) upon which people draw in pursuit of livelihoods.

F = financial capital: the financial resources which are available to people (whether savings, supplies of credit or regular remittances or pensions) and which provide them with different livelihood options.

N = natural capital: the natural resource stocks from which resource flows that are useful for livelihoods are derived (e.g. land, water, wildlife, biodiversity, environmental resources.)

It is clear that transport interacts with many aspects and dimensions of a person's or a community's livelihood. For example, substantial benefits could be obtained if the labour requirements involved in collecting water, firewood or taking crops to market could be reduced. The provision of all-season road access could reduce the vulnerability of rural communities by removing seasonal isolation, and reducing transport costs and travel times to essential economic and social services.

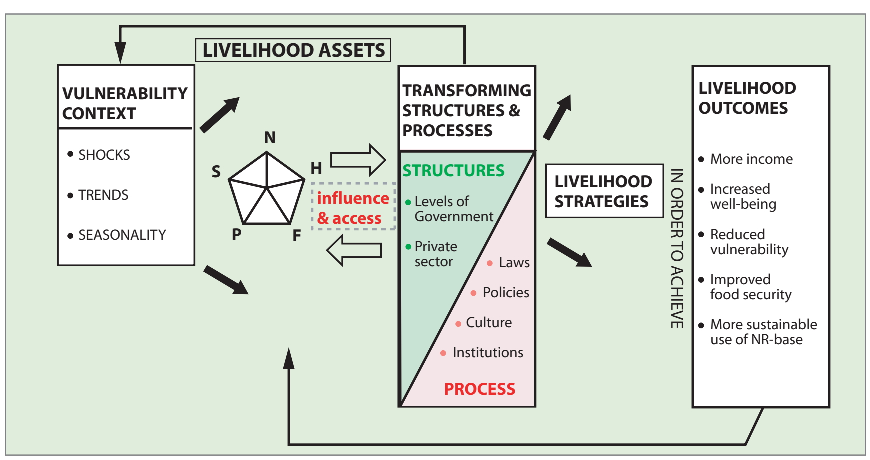


Figure 3.1 - Sustainable livelihoods framework

Integrated Planning Techniques for Transport

Master plans and the sustainable livelihoods approach are both general multi-sectoral planning tools but the specific focus is not on transport interventions. Transport may or may not be one of the interventions that are identified. However, there are a number of integrated planning techniques that specifically address transport issues. Their common thread is that planners need to address a range of issues in improving the accessibility of rural people to essential economic and social services through a combination of improved infrastructure, improved transport services and the improved location of the services themselves.

Integrated Rural Accessibility Planning (IRAP) was developed by the ILO[3] and is probably the most widely used planning technique of its type. IRAP has been used in many countries in the region, including Tanzania and Malawi. The approach integrates rural households' mobility needs, the siting of essential social and economic services, and the provision of appropriate transport infrastructure. Communities are involved at all stages of the planning procedure. It is based on a thorough but easy to execute data collection system that seeks to rank the difficulty with which communities access various facilities.

Box 3.3 - Integrated Rural Accessibility Planning

In this approach, an Accessibility Indicator (AI) is calculated for various facilities in each community. It is a function of the number of households (N), the average travel time to a facility (T), the target travel time (Tm) and the frequency of travel (F):

$$AI = N * (T - Tm) * F$$

Typical facilities included are health, education, water and fuel. The accessibility indicators are ranked in descending order and interventions are prioritised in this way. Results of this process are discussed at a participatory workshop and interventions identified which most effectively reduce time and effort spent.

Network-Based Planning

Traditionally, investments in roads have been evaluated on a link by link basis with less consideration given to the contribution that each link - competing for investment - makes to the connectivity or accessibility of the entire network. To overcome such short-comings, network-based planning approaches are increasingly being used to analyse the road system as a whole in order to prepare long-term strategic planning expenditure for road development and maintenance under various budgetary and economic scenarios.

Unfortunately, the situation confronting many SADC countries is one in which funding is available for maintenance of only part of the road network. In such situations it has become necessary to identify a "core road network" which is reviewed periodically and will expand or contract depending on local circumstances. Such networks often include roads of different classes that are considered to be an essential part of the total network so that links are maintained between all the communities throughout the country.

Models such as HDM-4 can be used for network-based planning purposes. However, as is often the case in many rural network situations, the necessary data required by such models are often not available, making such models inappropriate. Thus, procedures that involve a high level of stakeholder consultation are likely to be more effective for rural network planning purposes. However, there seems to be little information in the form of manuals on community-based network planning procedures.

Benefits of engaging in consultations with local communities at all stages of the project cycle include local knowledge of risks such as flood levels, location of resources, traffic flows, etc.

Stakeholder involvement in the decision-making process is critical for long-term sustainability of any road project.

3.2.6 Stakeholder Consultations

Why Have Stakeholder Involvement?

The objective of consultation is to ensure that the road planning process is undertaken in an accountable and transparent manner. This is important for the overall benefit of the affected stakeholders and for the country at large. Consultations should be carried out throughout all stages of the project cycle and should be undertaken in such a manner as to allow full participation of the authorities and the public with the following typical aims:

- establishing background information on the project from all possible sources
- identifying viable alternatives for the project
- taking on board the views of stakeholders at all stages of the project
- reaching a consensus on the preferred choice of project(s)

Decisions on transport planning and prioritisation in the SADC region have often been taken without considering the transport requirements of the people being affected by the investment. Insufficient consultation has led to the inappropriate use of resources both in terms of their usefulness to rural communities but also in terms of their impact on social and cultural traditions. To rectify this shortcoming it should be ensured that:

- local people are involved in the selection, design, planning and implementation of programmes and projects that will affect them
- local perception, attitudes, values and knowledge are taken into account
- a continuous and comprehensive feedback process is made an integral part of all development activities

Who are the Stakeholders?

Many people have an interest in road projects and all interested groups need to be identified and consulted in the road selection process. The primary stakeholders are those people whose social and economic livelihoods will be directly affected by the project and include:

- rural communities
- farmers group
- market traders
- transport operators

Some other interest groups are important in the decision-making process, even though their own lives may not be affected directly by the project. These include:

- district leadership
- district's works agencies
- national roads department
- local and national politicians

Because leaders' standpoints can differ significantly from the experiences of "average" village members, it is important for any consultation process to go beyond the leadership to the grass roots.

Consultation Techniques
There are a number of recognised participatory techniques for working with communities to determine their transport needs. These usually entail the use of trained facilitators to visually represent community livelihoods to identify constraints and needs. Typical techniques include:

- Participatory Rural Appraisal (PRA).
- Rapid Rural Appraisal (RRA).

Other methods include public hearings through political leaders, and direct community consultation. Workshops are often a good way of undertaking initial prioritisation exercises, delivering key messages and receiving feedback. It is important that all consultation techniques are well organised, that all the relevant stakeholders have been invited and that the deliberations take place in an interactive and transparent manner.

3.2.7 Surveys

Following from the first two phases of the project cycle there will be an initial selection of roads put forward for possible improvement and funding. Before final decisions can be made it is important to obtain information that is specific to the roads concerned. This involves conducting various road transport surveys which can help to pinpoint measures (technical, institutional and financial) for improving efficiency. These surveys may also provide supporting evidence for community perceptions on transport or, exceptionally, may provide some contradictory arguments that would need to be resolved. Participatory enquiry also supports a much greater focus on poverty issues and the role of transport in livelihoods[4].

Trafficability of unpaved roads is adversely affected during the wet season.

Trafficability versus Passability:

Trafficability: *A road is defined as having trafficability problems when the percentage of wet season traffic falls below 50% of the dry season traffic.*

Passability: *A road is defined as having passability problems when it is completely closed to motorised traffic for either part of or all of the year.*

Engineering Surveys
Engineering condition surveys need to be undertaken in order to identify the present condition of the road, the nature of proposed interventions, the quantities of work and the costs of the interventions and the future condition of the road. The interventions required for different treatments need to be identified and costed with the engineering surveys. It is important that alternative options are considered in the detailed appraisal.

Of particular importance to low-volume sealed roads is the provision of year round access and the social and economic benefits that arise from that. Therefore, it is important that there is some engineering judgement on the length of time that impassability or traffickability problems affect the road.

The term “trafficability” is relatively new and stems from research in Tanzania that showed that traffic levels tend to fall during the wet season even on roads in good condition. Typically, motorised traffic volumes will fall in the wet season to 80% of their dry season level. However, on poor quality roads this difference is even more marked and traffic can fall to 35% of dry season traffic levels, as shown in Figure 3.2. For the purposes of this Guideline it can be assumed that roads have traffickability problems when wet season traffic levels fall below 50% of dry season levels.

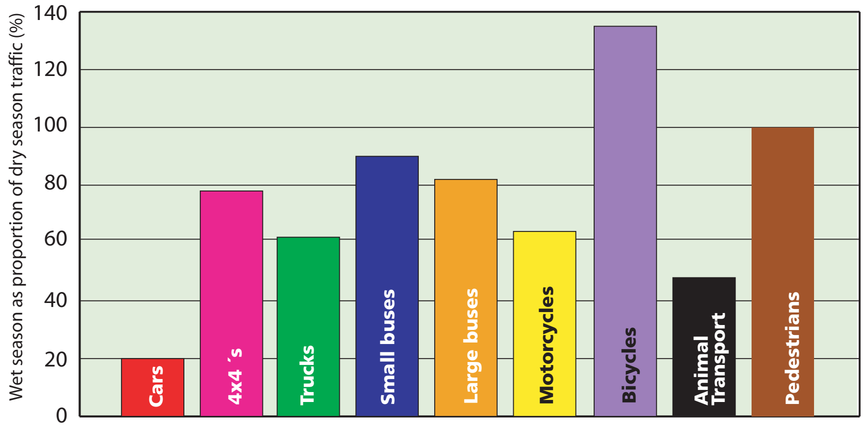


Figure 3.2 - The difference in wet season and dry season traffic levels on poor quality roads in Tanzania

Traffic Surveys

Traffic counts are one of the most important items of data for both geometric and pavement design as well as for planning purposes in terms of evaluation of economic benefits derived from construction of LVSRs. For these purposes, it is necessary to ascertain the volume and composition of current and future traffic in terms of motorcycles, cars, light, medium and heavy goods vehicles, buses, and, importantly, non-motorised vehicles and pedestrians.

The three most commonly used types of traffic surveys for LVRs are:

- Automatic Traffic Surveys.
- Manual Traffic Surveys.
- Moving Observer Methods.

Although the methods of traffic data collection may vary, the objective of the each method remains the same - essentially to obtain an estimate of the Annual Average Daily Traffic using the road, disaggregated by vehicle type. Prediction of such traffic is notoriously imprecise, especially where the roads serve a predominantly developmental or social function. Thus, the timing, frequency and duration of traffic surveys should be given very careful consideration in terms of striking a balance between cost and accuracy. As indicated in Figure 3.3, short duration traffic counts in low traffic situations can lead to large errors in traffic estimation and, in this respect, Moving Observer methods are likely to be particularly inaccurate.

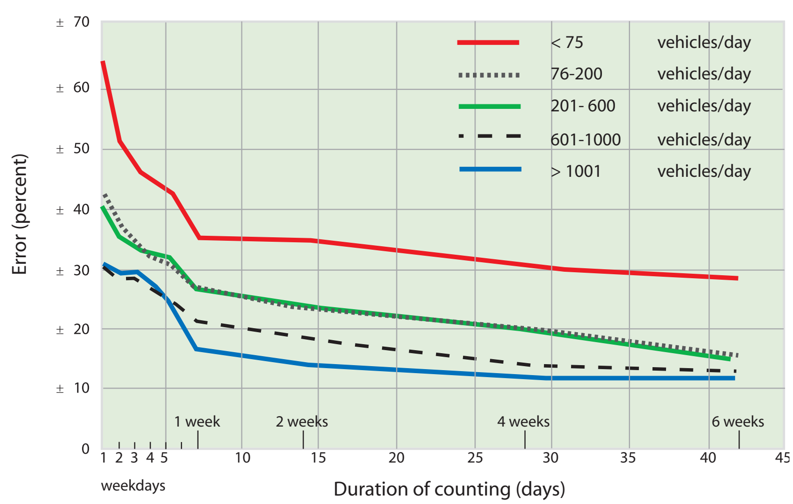


Figure 3.3 - Errors in ADT estimates from counts of varying duration[5]

The accuracy of traffic counts can be improved by increasing the count duration or by counting in more than one period of the year. Improved accuracy can also be achieved by using local knowledge to determine whether there are days within the week or periods during the year when the flow of traffic is particularly high or low.

Local knowledge should also be used to select appropriate locations for conducting the traffic counts to ensure a true reflection of the traffic using the road and to avoid under - or over-counting.

Origin and Destination Surveys, using a variety of survey techniques, are sometimes carried out to establish the nature of travel patterns in and around the area of enquiry. These surveys, which can be quite labour-intensive, serve a number of useful purposes including a quantitative assessment of the amount of traffic likely to be affected by the proposal and the consequent impacts on various elements in the road system.

Portable weighbridge system.

Axle Load Surveys

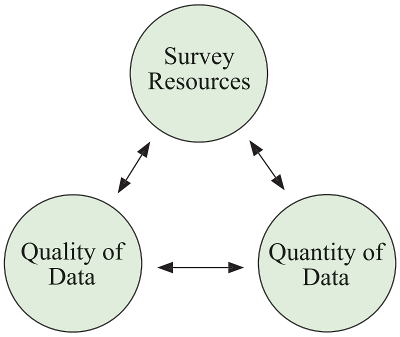
Axle load surveys provide critical and essential information that is required for both cost-effective pavement design as well as preservation of existing roads. The importance of this parameter is highlighted by the well-known "fourth power law" which exponentially relates increases in axle load to pavement damage (e.g. an increase in axle load of 20% produces an increase in damage of about 120%).

Axle load surveys can be expensive to undertake and should be carefully planned and organised in relation to the level of resources that can be committed to the survey (time, personnel and money) and the objective of the survey which could be:

- determination of vehicle equivalence figures (pavement design)
- overload control (pavement preservation)

The type of equipment which may be used for axle load surveys also varies widely and includes:

- static or dynamic weighing equipment
- manual or automatic recording of loads
- portable or fixed installation



Trade-offs in undertaking an axle load survey.

The quality of the data obtained will depend on the type of equipment used, the duration of the survey and the degree of quality control performed. In general, the higher the quality of the data, the greater will be the resources required to collect them.

There is an almost inevitable trade-off between available resources and the accuracy obtainable from a sample survey. The art of good survey design is to know when the optimal value for money from the survey is achieved. Further constraints exist for the data analysis stage. Some analysis techniques require expertise, computer hardware and software which may not always be available. Thus, the choice of analysis procedures may also involve trade-offs.

Measurement of rear axle load using portable weighbridge.

Axle load survey in progress. Such surveys are typically carried out over a 24 hour period for seven days.

Ultimately, an appropriate choice of equipment should be made in relation to such factors as:

- accessibility to back-up support (technical and maintenance)
- ease of installation and use
- accuracy of measurement required
- acquisition and operational cost of equipment

It is also important that axle load surveys are carried out in a systematic and standardised manner and separated from weighbridge measurements undertaken for the purpose of enforcing axle load limits. Guidelines currently exist in a number of SADC countries for carrying out axle load surveys.

Box 3.4 - Minimum information typically derived from axle load surveys

- Axle loads of all heavy vehicles whether empty or loaded.
- Vehicle category.
- Loading in each direction of the road.

Each axle in a multi-axle combination shall be measured separately. The survey point should also be equipped with sufficient capacity to weigh all heavy vehicles that are passing in one direction at a time, both empty and loaded.

3.3 Appraisal

3.3.1 Investment in LVSRs

The road sector consumes a considerable part of the overall infrastructure investments made in the SADC region and, with an increased focus on poverty reduction, there is an increasing emphasis on those for LVSRs. However, investment in such roads should be based on a set of clearly understood needs for them. *The process of establishing those needs requires detailed consideration of both the economic and social roles of roads and these, in turn, must be seen in the context of larger community needs for accessibility and mobility.* Certainly the provision of roads will be only one of the mechanisms used to satisfy those needs.

The various short-term effects and longer-term impacts of such road investments may be depicted roughly as shown in Figure 3.4. They are not just a progression in time, they are also a progression in certainty with the more distant developments being more difficult to achieve and less certain to materialise.

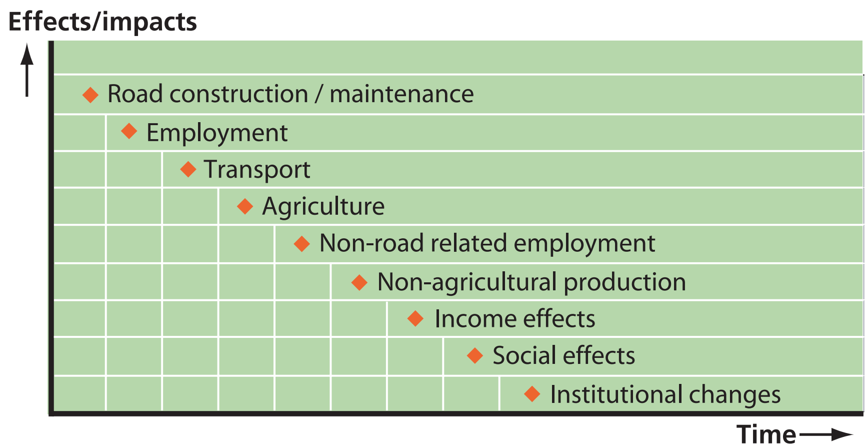


Figure 3.4 - Effects and impacts of road investments over time[6]

From the perspective of investment in roads only, employment is regarded as certain. ***Such employment, and thus the potential for assisting the poor, is obviously enhanced by the use of labour-based methods.*** With the exception of employment, all the rest of the other effects and impacts are indirect. Whether they occur or not depends on two factors:

(1) that traffic materialises as a result of the road improvement
(2) that this traffic is operating more efficiently

3.3.2 Life-Cycle Costing

Having identified a short list of projects, it is the purpose of an economic appraisal to ensure that the options considered represent a cost effective way of delivering the road. Appraisals driven by economic requirements will be relatively easy to identify via benefit-cost analyses. However, traditional appraisal frameworks do not cater well for economic justification of LVSRs as poverty reduction and other social benefit issues are more difficult to quantify and tend to be ignored.

Life-cycle costing uses economic evaluation techniques to select, from a series of options, the most economically appropriate new road project and the maintenance and/or rehabilitation treatment to be applied to an existing road.

In traditional approaches to undertaking an economic analysis, the basic objective is to determine the optimum mix between the costs of the project (related to the design standard) and the benefits from the project in terms of transport cost savings and other secondary benefits such as social and environmental benefits. The purpose is to find the investment option that ***minimises life-cycle costs.***

Figure 3.5 shows the conceptual total road transport cost curve which is made up of the construction/rehabilitation costs, maintenance costs and road user costs. It shows that as construction/rehabilitation costs increase (because of higher design standards) road user costs are typically reduced. The optimum road design standard is attained when the sum of the project costs are minimised. This optimum standard varies in relation to traffic level and the associated relative mix of construction, maintenance and user costs.

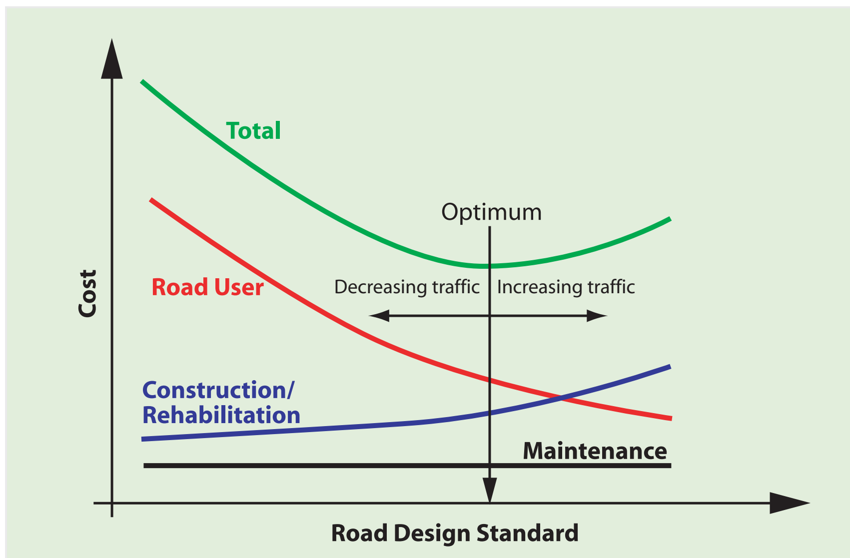


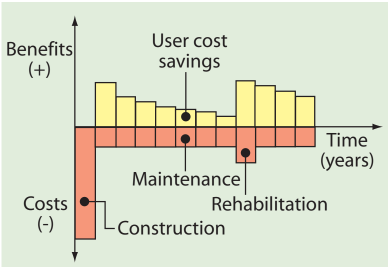
Figure 3.5 - Economic analysis of optimum road design standards

For a given traffic level, if the road were to be constructed to a standard higher than the optimum, then the benefits derived from a reduction in road user and maintenance costs would not sufficiently offset the costs of initial construction and the resulting investment would be sub-optimal. This highlights the importance of ensuring that appropriate standards are adopted in the planning, design, construction and maintenance of LVSRs. As might be expected, the optimum design standard for a LVR is lower than for a HVR.

Principles of Economic Appraisal

Several methods exist for the economic appraisal of road paving projects for which the primary objectives are to determine:

- the appropriate size of investment and the returns to be expected from this investment
- the appropriate geometric and structural design standards for the size of investment in order to obtain the expected returns
- the economic and socio-economic impact of investments such as the improvement to the community of industrial, agricultural, educational and health services



Distribution of costs and benefits during the life-cycle of a road option.

Through identifying, quantifying in monetary terms, and comparing the costs and benefits of different options, this technique is able to provide guidance on the design, prioritisation and selection of candidate road projects by addressing a wide variety of key decision-making issues. For instance:

- is the investment economically justifiable?
- if there are a range of alternative investments, which option gives the best economic returns?
- is the timing of the proposed project optimal?
- should components of the project be phased in over a period of time?
- how does risk and uncertainty affect the choice of projects?
- if funds are limited and there are many worthwhile investments, which should be built first?

An economic analysis considers the project from a national point of view. In an economic cost benefit analysis, the total costs and benefits that arise from a project are identified and measured, irrespective of who incurs the costs or benefits from the project. In contrast to a financial analysis, no monetary transaction needs to take place for an economic benefit or cost to be incurred.

Main components: The main components of an economic evaluation are as follows[7]:

- The identification of at least two different cases or scenarios; this will involve one ***base or "without investment" case*** and at least one ***project or " with investment case".***
- The ***planning time horizon*** i.e. the period over which the evaluation is made.
- An estimate of the project ***investment costs*** specified in ***economic price terms.***
- The ***benefits*** of the project or projects specified in ***economic price terms*** estimated from the differences in the costs of the with and without cases.
- A year-by-year determination of the costs and benefits of the different projects over their design lives, using discounted cash flow techniques to bring them all to their ***present value*** in terms of ***economic decision criteria*** such as NPV, BCR or IRR.

An investigation of how robust or reliable the results are through the use of ***sensitivity analysis*** or ***risk analysis.***

3.3.3 Quantification of Costs and Benefits

There are two principal methods of quantifying project costs and benefits in economic terms, the Consumer Surplus approach and the Producer Surplus approach:

(1) ***Consumer surplus approach:*** This is the orthodox approach to estimating the economics of road investments which assumes a reduction in transport costs arising from savings in vehicle operating costs[8]. The direct benefits to road users - the ***consumer surplus*** - equals the product of the number of trips and the cost saving per trip.

Transporting bananas and other food-stuff by bicycles.

The consumer surplus approach is normally used for those projects where traffic levels are likely to be sufficient for road user costs savings to justify funding of the project. The minimum traffic threshold which makes this approach appropriate to use is difficult to define beforehand but is likely to be of the order of 50 - 100 vpd.

(2) ***Producer surplus approach:*** In situations where no road exists and a substantial improvement in vehicle accessibility is planned to help develop an area, the producer surplus approach may be the most appropriate way of estimating agricultural benefits arising from road investment[9]. The producer surplus approach estimates the predicted benefits arising from the reduced cost of agricultural produce which will normally be the same as that predicted by a consumer surplus approach. However, when the producer surplus method is used, passenger benefits and other non-agricultural cost savings still need to be estimated separately.

The agricultural production and the size of the producer benefits are predicted from the rise in farm gate prices brought about by the decline in costs of transporting produce to market, as well as the decline in transport costs of agricultural inputs. However, several difficulties have been identified with the application of this method, including the need for substantial amounts of data, which may be either unavailable or of questionable reliability, and the fear of double counting. For such reasons, the use of the producer surplus method is not recommended unless there is a great deal of knowledge about agriculture and its likely response to changes in input and output prices.

3.3.4 Project Costs

There are two main areas to address in calculating project costs:

1) The project costs for a range of alternative infrastructure standards.
2) Technology choice and the options available from labour-based to equipment intensive.

The main project costs include:

- planning/design costs
- construction/supervision costs
- road agency costs (administration, operation and maintenance)
- road users' costs (VOC and TTC)

Construction and maintenance costs can vary significantly according to the standards to which the road is built. There are significant cost advantages from using the LVSR standards as set out in this guideline and it is important to have a detailed knowledge of these costs in the appraisal process. Table 3.4 gives the main options and the likely impact on construction costs.

Table 3.4 - Options for reducing construction costs

Option	Potential Benefits
Replacing a conventional geometric design process by a "design by eye" approach, where appropriate, and minimising deviations from existing alignments.	Reduced earth works and environmental damage. Earthworks can be typically 30% of total construction costs in rolling terrain.
Use of more appropriate pavement designs and natural gravel rather than crushed stone.	Reduced pavement costs due to lesser haulage distances and reduced materials processing costs.
Considering a range of infrastructure standards.	Allows an optimum standard to be adopted which minimises total transport costs.
Utilising an existing gravel wearing course e.g. as base or subbase .	Reduced haulage distances and materials costs.
Compacting subgrade and pavement layers to refusal, where feasible, rather than to arbitrary prescribed levels.	Increased density, reduced road deterioration and increased maintenance intervals.
Adopting appropriate surfacing technologies such as sand seals and Otta seals.	Reduced haulage distances, reduced processing costs.
Increasing the use of labour and local resources where appropriate.	Lower economic/financial costs for specific tasks.
Using seals as a spot improvement measure.	Reduced surfacing costs whilst maintaining year round access.

Short sections of road in poor condition can benefit significantly from spot improvement works.

The use of LVSR technology for spot improvements has, potentially, very significant applications on a wide range of roads that do not justify providing a seal over the entire length but could benefit from spot sealing works. These spots might include areas where there is significant seasonal difficulty in maintaining access such as on steep slopes or areas that are prone to flooding. They may also include stretches through towns and villages where, for social and environmental reasons, a sealed road would reduce dust nuisance and improve safety. Spot improvement strategies, particularly for the lower volume roads, provide a good way of meeting the planning objectives of maintaining basic access while minimising total transport costs.

3.3.5 Project Benefits

Changes in the *efficiency of transport* are the essential mechanism by which benefits from road building are transferred or released[6]. These changes are more than likely to occur with the sealing of an earth/gravel road in the form of a reduction in vehicle operating costs (VOC). However, other benefits of a broader socio-economic nature are also likely to occur and, by meeting specified social objectives, offer scope for achieving poverty reduction.

The benefits arising from the upgrading of a LVR typically include:

- developmental benefits - such as benefits to generated traffic
- social benefits - access to facilities through improved passability
- road user cost savings - such as reduction in VOC and TTC
- road agency benefits - such as reduction in maintenance costs

In general, the more competitive and less distorted an economy, the more likely that the primary benefits will cover the full consequences of a road investment. However, for the purpose of this Guideline, there is a case for including secondary benefits, particularly in circumstances where:

- existing traffic volumes are relatively low
- new road investments are made in remote rural areas
- a relatively large change in transport costs is anticipated
- there are unused resources

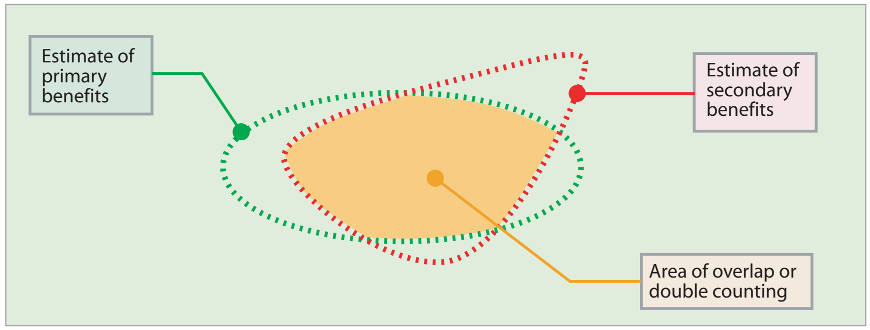


Figure 3.6 - Overlap of primary and secondary benefits

Social Benefits

Social benefits are not only some of the most difficult to quantify but, also, there is no universally agreed method for incorporating them within an economic analysis. Furthermore, a simplistic addition of social and economic benefits is likely to lead to problems of double counting.

The following provides some of the options that could be considered for incorporating social benefits within an economic analysis.

(1) Where roads suffer from impassability or trafficability problems there will be additional benefits from improved road provision that create year round access. The principal social benefits come from improved access to health facilities and education services, employment opportunities and social interaction. Little research has been done on the best way to quantify these benefits but practical approaches have tended to factor up conventional VOC savings for the period a road suffers either passability or trafficability problems.

(2) It is possible to identify key social criteria such as targeting the poorest areas, reducing isolation to basic services and markets. These would have to be identified on a project by project basis following consultation with all the relevant stakeholders. In a similar way to the approach indicated above, VOC benefits could be factored up if the improvement of a particular road met these social criteria.

(3) Benefits from education and health facilities can be estimated from improved access and the resulting improvements from income earning opportunities. For example, benefits from increased school enrolment levels can be estimated based on higher life earnings of the children who would have otherwise remained unskilled. Health benefits can be assessed based on reduced sick days away from work and the associated net income. However, such an approach may involve considerable field data collection and analysis.

(4) Quantifying social benefits in the same units as economic benefits[10]. In this approach, it is assumed that the population within a distance of 5 kilometres on either side of the road will receive social benefits as a result of the road improvement. In so doing, social factors are converted to the same units as VOC savings.

Research from Tanzania suggests that, on average, just over 30% of the total tonne kilometres is carried by non-motorised transport on low-volume roads. This figure ranged from just over 8% for higher volume roads (over 150 vehicles per day) to over 60% for the lowest volume roads (less than 10 vehicles per day).

Benefits to Non-Motorised Traffic

In many SADC countries non-motorised traffic constitutes a significant proportion of the traffic on low-volume roads and, in many cases, this traffic represents the majority of total tonne kilometres. *Benefits to non-motorised traffic represent significant savings that are not captured in a conventional consumer surplus analysis and therefore, alternative methods need to be considered.*

Although there has been limited research into the impacts of road improvements on non-motorised transport there are a number of sources of information that will help planners to make estimates of the potential benefits. Table 3.5 sets out the sources and the type of information available.

Table 3.5 - Sources of information for non-motorised transport

Source of information	Type of information
Roads Economic Decision Model (RED)[11]	Calculates VOCs for pedestrians, animal carts, and bicycles.
Appraisal of investments in improved rural access. Economist guide[12]	Contains a number of mini-guides including one on calculating VOCs for non-motorised transport based on HDM 4 relationships.
A handbook of rural transport vehicles in developing countries[13]	Contains look-up tables for a wide range of motorised and non-motorised vehicles for different infrastructure quality and distances.
Ghana prioritisation procedure[14]	Provides VOC savings for bicycles and pedestrians following road improvements.

Where estimates of benefits to non-motorised transport are available it is appropriate to add these to the benefits from motorised transport.

3.3.6 Cost-Benefit Analysis

Use of Investment Appraisal Models

The primary function of a road investment appraisal model is to calculate the costs and benefits of road construction, road maintenance and road user costs for a specified analysis period. This is accomplished by modelling the interrelationships between the environment, construction standards, maintenance standards, geometric standards and road user costs. Such models can be used to perform a number of economic analyses, one of which is to identify unpaved roads that may be potential candidates for paving.

Typical components of a life-cycle cost analysis are shown in Figure 3.7 for a ***base or "without investment" case*** (gravel road) and a ***project or "with investment case"*** (paved road).

In very general terms, paving a gravel road will be economically justified when the net present value (NPV) of the sum of savings in VOCs and maintenance costs, relative to a well-maintained gravel road, is at least as great as the NPV of upgrading costs. Where not captured in the investment appraisal model, socio-economic benefits will need to be evaluated separately after the economic appraisal has been carried out.

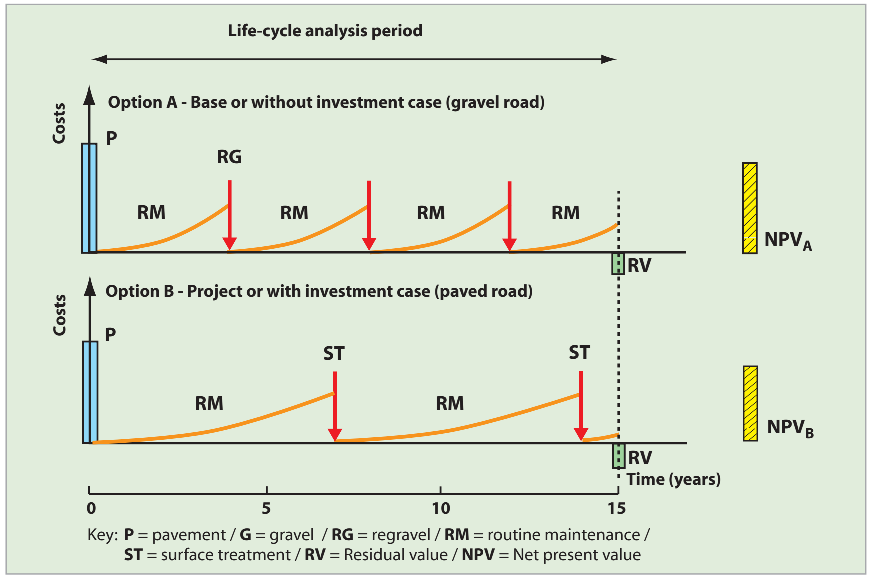


Figure 3.7 - Typical components of a life-cycle cost analysis

Characteristics of Main Project Types

Candidate projects for upgrading typically fall in the following categories, viz:

- Basic accessibility projects: including upgrading tracks and earth roads to gravel roads.
- Mobility projects: (a) bitumenising existing gravel roads
  (b) strengthening/expanding capacity of existing bitumenised roads

Investment in the above types of project is generally motivated by quite different reasons and yields quite different types of benefits. For convenience, these project types may be categorised in relation to broad traffic bands as follows:

Category I – less than 50 vpd: Investments in this category of road are usually poverty-targeted with a focus on social rather than economic objectives. Thus, a least-cost or cost-effectiveness approach is usually adopted and investment models are generally not appropriate for such roads[15].

Category II – 50 to 200 vpd: (Primary focus of this Guideline): Investments in this category of road give rise to a mix of economic, social and environmental impacts depending on their function and level of traffic carried, which can include a significant proportion of non-motorised traffic.

Category III – more than 200 vpd: investments in this category of road give rise to predominantly economic impacts in the form of reduced transport costs, as well as to environmental impacts.

Suitability of Investment Appraisal Models

The economic evaluation of donor-funded road projects in the SADC region generally requires the use of an internationally recognised investment model. The following models which adopt the *consumer surplus* approach have been used for that purpose:

- Road Transport Investment Model (RTIM) developed by the UK Transport Research Laboratory[16].
- PIARC's Highway Development and Management Model (HDM-4)[17].

Unlike models such as the South African CB-Roads[18] and SURF[19] models, which were developed specifically for local conditions, models such as RTIM and HDM were developed to be applicable in a large number of countries covering a wide range of conditions. Moreover, they are the result of the collaboration of a number of international organisations and, as a result, the latest version of the HDM model, HDM-4, has become the *de facto* model for use in the region, together with a more recently developed and simplified derivative, the Roads Economic Decision Model (RED)[10].

Whereas the HDM-4 model presents a very good framework for the economic analysis of road investments, it is neither customized for LVRs nor does it capture all the benefits associated with such roads. In contrast, RED has been customized for LVRs and offers a number of other advantages which are contrasted with HDM-4 in Table 3.6.

Table 3.6 - Comparison of HDM-4 and RED appraisal investment models

Model	Advantages	Disadvantages
HDM 4	• Globally used model. • Extensive research on VOC and deterioration relationships. • Can be used for strategic planning i.e. can assess networks. • Now includes NMT.	• High data requirements. • Does not include social benefits[1]. • Cannot deal with passability and trafficability issues. • Road roughness is often not an appropriate measure of condition for LVRs. • Not well suited for low traffic levels.
RED	• Has limited data requirements. • Can accommodate NMT and some social benefits. • Can be run from a spreadsheet. • Can accommodate impassability issues. • Can be used for ranking projects. • Well suited for traffic levels in range 50 – 200 vpd.	• NMT categories are limited to four. • Would have to be calibrated for Low-volume sealed roads.

1 – to be included in a later version

Table 3.7 provides a general guide to the applicability of commonly used investment models in the SADC region for evaluating LVSRs. The preferred choice of model depends largely on the nature of the impact triggered by the investment intervention.

Table 3.7 - Applicability of investment models to LVSR evaluation

Factor		Project Type		
		Access	Mobility	
			Basic	Advanced
Motivation		Social	Socio-economic	Economic
Traffic band		< 50 vpd	50 – 200 vpd	> 200 vpd
Traffic type		NMT	NMT - MT	MT
Relative benefits	Social	High	Medium	Low
	Economic	Low	Medium	High
Appropriate model		Least Cost	RED	HDM-4

Least Cost Approaches

The goal of the Least Cost Approach is to employ the most appropriate and cost-effective intervention which provides a minimum level of reliable, all-season passability for the locally prevailing means of transport.

As indicated in Table 3.6, those road improvements in which economic impacts are dominant (traffic is typically > 200 vpd and is predominantly motorised) are best evaluated by investment models such as HDM-4. However, at lower traffic levels (traffic typically 50 - 200 vpd) where NMT is significant and social benefits are dominant, RED would be the more appropriate investment model to apply.

3.3.7 Ranking Methods

Ranking Methods are important for two reasons. First of all it is unlikely that funds will be sufficient for all projects that are economically or socially justified and hence projects need to be placed in an order of priority. The use of investment appraisal models can facilitate this. Secondly, as discussed above, some important benefits cannot be easily quantified and may not be included in appraisal models. Therefore ranking methods that allow such benefits to be taken into account in the appraisal process are essential if the 'best' projects overall are to be selected for implementation.

Multi-criteria Analysis: These methods adopt a multi-objective approach which seeks to incorporate both economic and non-economic goals into an evaluation framework[20]. The approach assumes that the full set of attributes characterising a project cannot be expressed by a single parameter. Instead, the framework should include a number of criteria for evaluating the project in socio-economic terms such as economic benefits, economic costs, distribution of economic benefits, accessibility to social services, employment, etc. Quantitative measures of each of these criteria must then be defined in their own units to facilitate transforming the spectrum of physical measures for each criterion into utility value terms. Completion of the utility analysis depends upon the decisionmaker's articulation of his preferences amongst the various criteria.

As with other planning systems it is important that communities are fully informed both in the selection of relevant criteria and in the subsequent results. Problems may arise where consultation has not taken place or where the complexity becomes too great because of too many variables.

The advantage of adopting such an approach is that a number of factors can be included to reflect wider political and socio-economic needs. However, the disadvantages are that the addition of other factors complicates the analysis and more data needs to be collected.

Compound Ranking Methods: These methods rank projects according to factors that are considered to be relevant to the investment decision rather than derive economic benefits that can be used in a cost-benefit analysis. The approach enables social and political factors to be considered alongside economic factors and is based on the following principles[21]:

- factors included should reflect the objectives of the investment programme
- each factor is measured in its own units (for example, number of people gaining access to services)
- factors are weighted to reflect their impact on the programme objectives

Compound ranking methods utilise a points scoring system which is rather subjective. They are probably most appropriate when non-economic objectives are part of the investment objectives for which a "least cost" approach would be adopted.

3.3.8 Implications of Using Revised Approaches

The implications of using the revised approaches recommended in this Guideline are a significant reduction in both the initial construction and longer terms maintenance costs. Coupled with the use of an investment model which is able to quantify important socio-economic benefits, the effect is to reduce the threshold level at which it is economically justified to pave an earth/gravel road (see Table 3.8).

Table 3.8 - Factors influencing the traffic threshold for upgrading

Parameter	Impact
Use of more appropriate pavement designs	Reduced costs
Use of more appropriate geometric designs	Reduced costs
Increased use of natural/unprocessed gravels	Reduced costs
Quantified impacts of depleted gravel resources	Reduced costs
Benefits from non-motorised transport	Increased benefits
Quantified adverse impacts of traffic on gravel roads	Increased benefits
Reduced environmental damage	Increased benefits
Quantified assessments of social benefits	Increased benefits

The impact of these factors is illustrated conceptually in Figure 3.8 which reflects the outcome of recent research[22] and indicates that, in some circumstances, bitumen sealing of gravel roads is economically justified at traffic levels of less than 100 vpd. This is in contrast to the previously accepted figures for Sub-Saharan Africa, which indicated that it was only economic to provide a bitumen surface at traffic levels over 200 vpd.

The Net Present Value (NPV) is simply the difference between the discounted benefits and costs over the project analysis period. A positive NPV indicates the project is economically justified at the given discount rate.

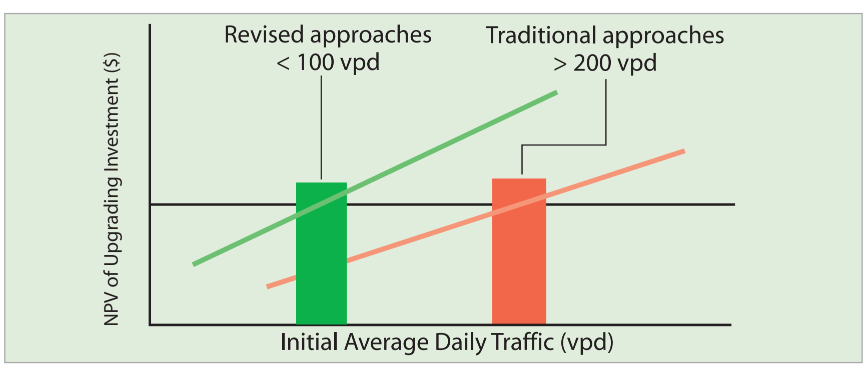


Figure 3.8 - Break-even traffic levels for paving a gravel road: Traditional versus revised approaches

3.4 Environmental Issues

3.4.1 Introduction

Any development brought about by man, such as the construction of roads, inevitably produces an impact on the environment. In practice, therefore, it must be accepted that modifications to the natural environment are an inevitable result of attempts to achieve social and economic progress, alleviate poverty and improve human welfare.

LVSRs in the region are generally constructed to improve the economic and social welfare of those using the roads or served by them. By their very nature, such roads are agents of change which can bring both benefit and damage to the existing balance between people and the environment. In the past, the attention of many SADC countries was focused almost exclusively on the potential benefits from these new or improved road facilities. In contrast, the resulting environmental problems have received little attention, largely because they were considered to be either unimportant or the price to be paid for development[23].

Safeguarding the future

All human activity depends on the Earth and its natural resources, but it sometimes threatens the delicate balance of the environment. The greatest challenge we face today is to bring about improvements in the living conditions of millions of people while protecting and safeguarding the environment for future generations.

Overseas Development Administration (ODA), UK. Action for the Environment. May 1992.

More recently, all SADC governments have become increasingly conscious of the impact of unbridled development on the environment and the recognition that, in the long term, environmental conservation and economic development are not only compatible but interdependent and mutually reinforcing. This has raised a number of issues which must now be faced in an attempt to create a balance between much needed development on the one hand and environmental care on the other.

This section considers the environmental issues facing road authorities in the SADC region with a focus particularly on LVSRs. The importance of establishing appropriate policy guidelines and the role of environmental impact assessments in LVSR provision is considered together with the main environmental impacts likely to be encountered and mitigating measures for overcoming them.

3.4.2 The Environment

In its broadest sense, the term *environment* includes both the natural or "bio-physical" environment (flora, fauna and physical features) as well as the human environment (socio-economic and cultural factors) and the interaction between them. As illustrated in Table 3.9, there are four key cornerstones of the environment:

- ecological
- economic
- social and
- physical

Each of the cornerstones of the environment includes a range of factors which should be considered at all stages of the planning cycle, as discussed further in this chapter.

What price the environment?

The environment is not a free resource in infinite supply. It provides a wide range of services which underpin all productive activities and contributes to human welfare in a number of direct ways. Although it may not be possible to put a conventional price on the environment, it still has a value for those who work and live in it.

Elephants crossing a main road that traverses a game park.

Un-renovated borrow area - typical of many countries in the SADC region.

Table 3.9 - Cornerstones of the environment

ENVIRONMENT	• Ecological	- impact on flora and fauna - deforestation - disturbance of natural eco-system - decrease in bio-diversity - threats to exotic and non-indigenous species - depletion of scarce material resources - regressive or progressive soil erosion
	• Economic	- capital costs (design and construction) - maintenance costs - flood damage costs - loss/degradation of agriculture/arable land - sterilisation of land for future use - land value reduced (designated borrows, severed farms)
	• Social	- severance/dislocation of local communities - adverse impacts on women - destruction of cultural antiquities - conflicts arising from changing land use/ownership of land - traffic accidents - health and safety (e.g. danger to humans, especially children, and wildlife from drowning in borrow pits) - construction impacts
	• Physical	- aesthetic - e.g. loss of natural beauty and scars on landscape - natural vegetation is not, or cannot, be replaced - noise, air, water pollution - dust impact - disruption of drainage courses

3.4.3 Typical Causes of Environmental Problems

The following are typical causes of environmental problems related to the provision of LVSRs.

- ***Design defects:*** These create problems when they are not anticipated and the project fails to include remedial measures. For example, measures taken to keep water off the road can cause problems elsewhere. Upstream preventative measures can interfere with natural river flows. Drains concentrate and speed up flow, sometimes causing flooding and soil erosion downstream.

- ***Poor project documentation:*** Unless remedial measures are clearly reflected in project documents (e.g. Terms of Reference or contract documents) they may not be fully implemented. This often results from use of standard contract documents which do not allow for the special circumstances of the project. For example, standard contract documents for roads often include specifications requiring the contractor to “cut and dispose of soil within the transverse profile”, or to “carry surplus material to spoil”. When such specifications are inadvertently applied in steep, mountainous terrain - particularly if hillsides are intensely cultivated - the dumping of soil over the edge of the road formation can have devastating results.

- ***Presence of construction activities:*** Temporary site works are typically characterised by borrow pits, ruts in the road created by vehicle wheels and drainage ditches which provide ideal breeding grounds for insects (particularly mosquitoes). Construction workers may kill local fauna for the pot, while the canteen refuse normally associated with construction camps encourages the proliferation of insects and vermin. One of the most serious diseases spread by construction crews in many SADC countries is malaria. Such impacts can generally be avoided by including appropriate remedial measures in contract documents.

- ***Weak environmental institutions:*** Successful remedial measures depend on the effectiveness of local environmental institutions, including those dealing with the regulation of land-use. For example, when new roads are being constructed in undeveloped areas, it should be mandatory for the project to be cleared by the local planning agency responsible for dealing with the planned and spontaneous development that may occur in response to the project. However, such provisions will only be effective if the local environmental agency has the skills, manpower and authority to ensure that the contractor complies with the requirements. If the poor performance of local environmental institutions is likely to affect project implementation, this should be evaluated and attended to before the project is approved.

Gravel stockpile for road construction - causes gradual depletion of a finite, non-renewable resource - an unsustainable activity.

The Special Case of Borrow Pits

The extraction of substantial amounts of non-renewable natural resources for road construction in SADC countries is over 150 million cubic metres per annum and has the potential to create significant damaging effects (negative impacts) on the local environment and its inhabitants.

Box 3.6 - Specific impacts of borrow pits in the SADC region

- Material resources:
  - permanent loss of natural resources
- Morphological damage:
  - modification of the natural drainage
  - increased soil erosion and siltation of watercourses by disturbance of soil
  - destabilisation of slopes
- Ecology:
  - loss of wilderness and forest
  - displacement of species and habitats
  - loss of potential productivity of agricultural land
- Pollution:
  - contamination of water and soil by fuel and oil spillage
  - generation of dust during the processing, loading and transporting of materials
  - increased dust generated by vehicles along access tracks
  - littering
- Social and health impacts:
  - creation of habitats for disease
  - landscape alteration and interference with natural beauty
  - bisection of communities or farms
  - loss of land legacy
  - loss of antiquities, cultural heritage, areas of cultural concern (e.g. graves)
  - hazards to pedestrians and animals, including open or unmarked trial pits, demarcation beacons, etc
  - safety risks to local population by exposure to heavy plant and traffic
  - noise of drilling, blasting, traffic and plant

Children exposed to risk of drowning and poor quality water. Ponding and poor drainage also increases the level of mosquito-borne disease.

Very often, worn out construction plant is abandoned and becomes an eyesore. The contract documents should cover removal of unwanted plant to an approved area.

Other environmental impacts associated with the construction of roads in the SADC region include:

- hard rock quarries
- river bed gravel pits
- hill slope pits

Recent surveys carried out by the UK Transport Research Laboratory[24] in two countries have shown that:

- Historically, restoration of borrow pits has been the exception rather than the rule. On average, only around 15% of borrow pits are restored after extraction of materials.
- The environmental damage caused by improper extraction and rehabilitation practices can extend over a wide area and may only become apparent after project completion. Examples include soil erosion causing siltation of natural water courses. Around 50% of worked borrows had excessive land erosion.
- Environmental damage caused by pits is often most severe in areas important for subsistence farming. Only 4% of land previously used for farming was under cultivation after extraction of material.
- Contractors often leave pits open at the request of the land owner, because these are seen as a useful mini-reservoir to provide water for animals, washing and bathing. However, this practice poses severe risks to humans caused by exposure to stagnating water and mosquito borne disease.

Borrow pit rehabilitation

(a) Original pit used for construction.

(b) Borrow pit rehabilitation in progress after one year.

(c) Full rehabilitation of borrow pit achieved after 3 years.

Following on from the TRL survey, improved guidelines for borrow area management have been developed[24]. These guidelines consider:

- planning and access issues
- top soil and overburden removal and stockpiling
- rehabilitation procedures and disposal of soil
- safety (e.g. health and disease, warning signs and fencing, littering and fuel spillages)

The guidelines also contains advice for use in contract documents.

3.4.4 Environmental Impact Assessments

Responsibility for applying sound environmental policies rests with the executing agencies in the SADC region, usually the roads agencies, guided and assisted by environmental units within the agency. However, increasingly, dedicated environmental Departments and Ministries are being established. In carrying out these responsibilities, staff should be guided by the overarching objective of ensuring that projects are designed and implemented according to sound principles which minimise adverse impact and enhance benefits. A variety of procedures need to be followed at various stages of the project cycle in order to achieve these objectives. These procedures normally involve some kind of environmental impact assessment (EIA).

The EIA Process

EIA is not an outcome. Rather, it is a process for improving the quality of the outcome and can be applied to any proposal[25]. The process is flexible and adaptable and can be tailored to suit the circumstances of any road project. In essence, an EIA evaluates foreseeable impacts, both beneficial and adverse, and helps to reveal mitigating measures and alternatives as well as to optimise positive impacts while reducing or limiting negative impacts.

Road upgrading requires careful planning to minimise adverse impacts on the natural environment.

The main components of the EIA include:

- establishing the need for the project
- identifying and quantifying the full range of potential impacts on the natural and social environments
- formulating remedial procedures for avoiding, mitigating and compensating for these impacts
- reflecting remedial measures in the project documents
- ensuring that remedial measures are complied with during the project implementation

The EIA process is usually integrated into the project cycle as a means of improving the quality of the outcome. Community involvement in this process is important and necessary as it seeks to solicit information, views and concerns that only the affected community can provide. It can take many forms and fit into the process at any or all stages depending on the type of project. It can involve a broad range of interest groups and individuals or it may only require limited involvement. The process is set out in outline in Table 3.10.

Table 3.10 - A framework for EIA

Phase of project cycle	Activity	Objective
Project identification	Initial screening	- register "danger signals" - avoid unnecessary investigation where impacts are likely to be minimal
Feasibility	Environmental appraisal	- predict main impacts - assess importance of effects - indicate key mitigating actions required - present implications to decision makers
Design	Environmental impact assessment	- predict in detail likely impacts, including cost implications - identify specific measures necessary to avoid, mitigate or compensate for damage - present predictions and options to decision makers
Commitment & negotiation	Environmental enforcement	- ensure environmental mitigation measures are included in the contract documents
Implementation	Environmental monitoring	- ensure environmental mitigation measures are being complied with during construction
Operations and maintenance	Environmental audit	- assess the extent of implementation of a project against the requirements derived from the EIA - ensure lessons learned are incorporated in future projects

The output of the EIA is often formalised into an *environmental impact statement* (EIS) which, in some SADC countries, is mandatory for many road projects. Such a report would typically cover the following:

- brief description of project
- brief description of existing environment
- likely impact of project

- mitigation and protection measures
- consideration of “no change” alternative
- summary and conclusions

The EIS should provide a better understanding of the linkages between society, the natural environment and the sustainable use of inherited resources.

An important component of the EIA is the *environmental audit* which seeks, in essence, to assess the implementation of a project against requirements derived from the EIA. The audit can be viewed as a “snap-shot” of the environmental situation at a given site and at a given time. It does not attempt to predict the potential impacts of planned investments but, rather, to serve as a source of baseline information which may complement or substitute for normal EIAs, depending on the type of project.

Box 3.7 provides an example of a checklist of issues that would typically be considered in an EIA for a LVSR.

Box 3.7 - Typical check-list of issues to be considered in an environmental impact assessment for LVSRs[7]

Consequential developments: Will the project stimulate land clearance for agriculture, the development of industry or mineral extraction? What steps can be taken to mitigate long-term adverse effects?

Social factors: Has adequate provision been made for vehicle, pedestrian and NMT safety? Are the geometric standards adopted likely to require additional safety countermeasures (e.g. signing, education programmes)?

Geotechnical damage: Has the project been designed to minimise the possibility of landslides and other geotechnical problems? Have long-term maintenance consequences been taken into account?

Materials resources: Will the project result in the unacceptable depletion of material resources that may be needed for subsequent maintenance or other construction projects? Will borrow pits be restored and can their effect on the landscape be minimised?

Drainage: Will the project result in increased risks from flooding or landslides as a result of disturbing natural drainage patterns? Will later development of agricultural land and other settlements affect hydrological conditions so that drainage works and bridges must be modified? Will any water impoundments create health hazards?

Ecology: Have the effects on animals and plants been considered? Has an ecological reconnaissance been carried out to assess effects?

Other factors: Are air pollution, noise and vibration, and visual intrusion issues of concern in the project? If so, what can be done to mitigate the effects?

Value of the EIA

Effective use of scarce resources is becoming increasingly important in a climate of decreasing funding and increased community demand for the improved efficiency and performance of SADC’s new generation of more autonomous roads agencies. In this regard, the EIA process offers the following benefits:

- alternative projects are systematically considered
- the decision-making process is more transparent

- environmentally significant issues are identified at an early stage
- a bridge is provided between the roads agency and the public it serves
- the community is reassured that its needs are being considered
- the roads agency is forced to consider the broader issues of its work
- local information provided through involvement of the community can improve the accuracy and relevance of the information collected for the project
- the risk of aborting a project at an advanced stage due to public dissatisfaction with the project is reduced
- interaction between technical, economic and environmental factors leads to optimum design and improved technical and economic efficiency

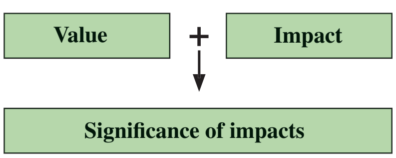
Legislative Aspects

The effectiveness and success of an Environmental Impact Assessment (EIA) depends on the extent to which it is actively used and incorporated into different stages of a normal project planning process. In most SADC countries, an EIA has become a formal legal or administrative requirement. However, there is a need in each SADC country to institutionalise the entire process of environmental management by setting up a duly constituted organisation with the necessary authority and legal backing to enforce government environmental policy.

Impact assessment is a systematic evaluation of the relevant advantages (benefits) and disadvantages (costs) that a new road plan or improvement of existing roads will generate regardless of the unit of measurement, i.e. whether measurable in monetary units or not.

3.4.5 Assessing Environmental Impacts

Assessing the likely effect of a road project on the environment can be accomplished through an EIA as described above. However, quantifying these impacts is more difficult. Unlike monetary impacts, non-monetary impacts cannot be calculated, assessed or compared with each other in a standardised manner. Nonetheless, non-monetary impacts should be considered in a transparent and accountable manner. An impact assessment procedure to evaluate each of the non-monetary impacts has been developed so that these can be considered together with or compared to monetary impacts[26]. The procedure is based on the following three factors:



General principle of assessing non-monetary impacts.

- value
- magnitude
- significance

When evaluating each of the non-monetised impacts the following steps apply:

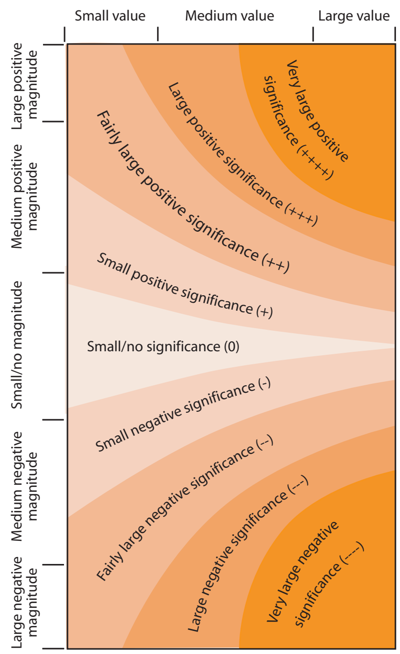
(1) Assess the value of areas influenced by the project and characterised with respect to the most important impacts.

(2) Determine the nature and magnitude of impacts through qualitative descriptors.

(3) Assess the overall significance of the impacts for the project.

The significance of the various impacts can be assessed by combining the value and magnitude of the impact. The general principle is that the larger the value and vulnerability of the project, the more significant is the impact, whether positive or negative.

A general scale for assessing the significance of the impacts is shown below, ranging from very negative (- - - -) to very positive (+ + + +) and is illustrated in Figure 3.9.



++++ Very large positive significance
+++ Large positive significance
++ Fairly large positive significance
+ Small positive significance
0 No significance
- Small negative significance
- - Fairly large negative significance
- - - Large negative influence
- - - - Very large negative significance

The horizontal axis measures value of impact while the vertical axis shows the magnitude of the impact. For example, an impact whose value is found to lie in the region "large value" and whose magnitude lies in the region "large positive", will have a significance factor described as very large positive significance. This implies that the road alternative will be positive with respect to the impact.

Figure 3.9 - A framework for assessing the significance of impacts on LVSR projects[26]

An example of the process of assessing the value of the natural environment, the magnitude of the impacts, as well as the significance of the impacts is shown in Figure 3.10.

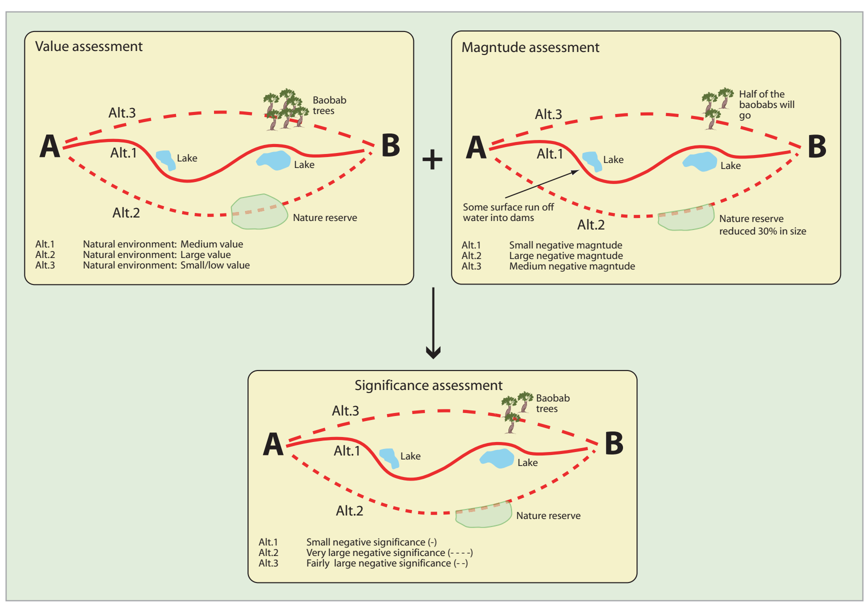


Figure 3.10 - Example of assessing value, magnitude and significance of impacts on LVSRs[27]

3.5 Summary

The key points arising in this chapter are:

1. Planning and appraisal procedures should consider a wide range of external factors, many of them of a non-technical nature, that affect the planning process if long-term sustainability of the investment is to be achieved.

2. Stakeholder consultations are critical in the planning process for which there are a number of techniques which should be undertaken as appropriately and as transparently as possible.

3. The traditional methods of investment appraisal are generally not adequate for capturing the full range of benefits - often of a social rather than economic nature - arising from the provision of LVSRs. More recently developed models, such as the World Bank's Roads Economic Decision (RED) model, are better suited for appraising such roads.

4. The implications of adopting cost-reducing measures, such as the use of more appropriate pavement and geometric design methods and wider use of natural gravels rather than crushed stone, in combination with the use of appraisal models, such as RED, are a lowering in the traffic threshold level for sealing an earth/gravel road from the previous figure of over 200 vpd to less than 100 vpd.

5. Environmental issues are assuming greater importance in the region than hitherto. Environmental impact assessments (EIA) should become an integral aspect of all LVSR projects. The effectiveness of the EIA will depend on the extent to which it is actively used and incorporated into different stages of the project planning process.

The important processes of planning and appraisal have been covered in this chapter together with environmental issues. Decisions made during the initial planning phase are particularly influential and have a high impact on the subsequent stages of LVSR provision, including those of geometric design and the associated road safety issues covered in Chapter 4.

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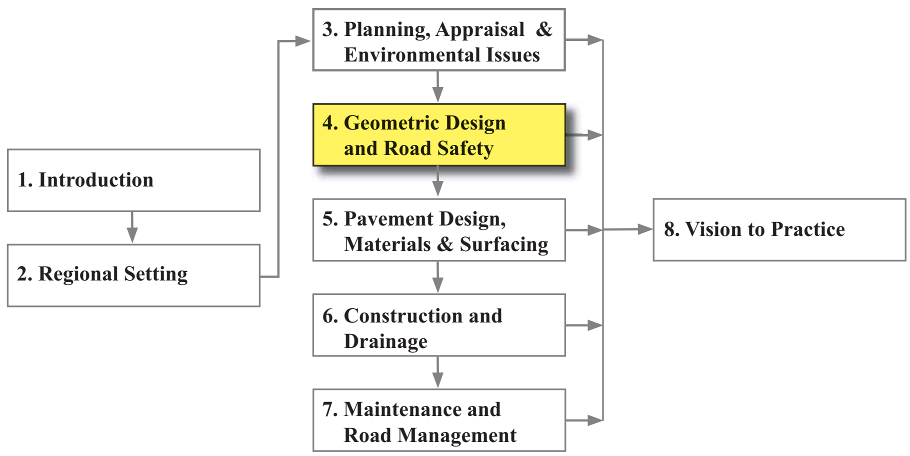
Chapter 4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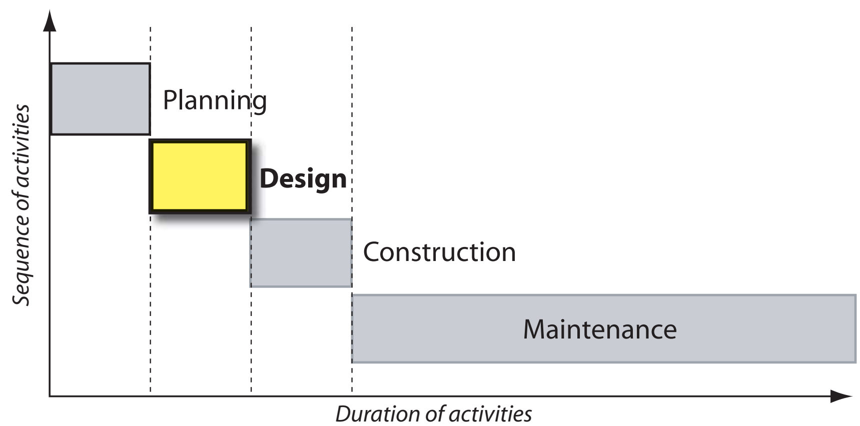
4.1.1 Background



Geometric design is one of the first stages of the LVSR design process that is normally carried out after the planning and appraisal stages. The outcome determines the construction requirements and influences the maintenance requirements. In the design process, the layout of the road in the terrain is designed to meet the specific needs of road users. This involves the selection of suitable road widths and horizontal and vertical alignments in accordance with appropriately prescribed standards which provide the following:

- minimum levels of safety and comfort for drivers
- a framework for economic design
- consistency of alignment

The design standards should take into account the road environment, road conditions, traffic characteristics and driver behaviour. In so doing, the design aims to provide a road with an alignment and cross-section that are not only the best compromise between operational efficiency, safety and economy but also minimises any adverse environmental and social/cultural impacts. This requires a thorough knowledge of the local road environment which affects every aspect of the design process.

It was only in 2001 that, AASHTO produced its "Guidelines for Geometric Design of Very Low-volume Local Roads (ADT ≤ 400)". This was in recognition of the fact that " …very low traffic volumes make designs normally applied on higher volume roads less cost effective." Prior to this, its "Policy on Geometric Design of Rural Highways - 1965 edition", which did not cater specifcally for low-volume roads, was the de facto standard adopted in most SADC countries!

Accident rates in the SADC region are of the order of 30 - 50 times higher than in Europe or the USA.

Severe erosion of side slopes that can lead to siltation of streams and rivers.

Geometric Design

The geometric design of LVSRs presents a unique challenge because the relatively low traffic levels make designs normally applied on higher volume roads less cost effective. Unfortunately, design standards for LVSRs have never been specifically developed for the SADC region. In the absence of such standards, there has been a tendency to use national standards that are based on those developed in industrialised countries, such as the traditionally used AASHTO *Policy on Geometric Design of Rural Highways*[1].

Imported standards tend to cater for relatively high levels of traffic and embody relatively high levels of service, as a result of which they are often inappropriate for application to LVSRs. Moreover, they give little, if any, consideration to the use of labour-based methods of construction which can influence the design process (ref. Box 4.1). This results in LVSRs often being designed in a manner that does not take account of the socio-economic and other characteristics of the local road environment.

Road Safety

Many aspects of the geometric design process are affected by the road environment which, in turn, can influence the level of road safety provided to road users. Experience has shown that simply adopting "international" design standards from developed countries will not necessarily result in levels of safety that are achieved in those countries as these are generally accompanied by effective enforcement, driver training and publicity - influences that are often not operating as efficiently in the SADC region.

Road traffic operations also tend to be complex and often involve a mixture of motor vehicles, bicycles, animal drawn vehicles and pedestrians. A large proportion of the traffic composition is dominated by relatively old, overloaded and slow-moving vehicles and there are often low levels of driver training and control of road users. In such an environment, traffic safety assumes paramount importance, an aspect of geometric design which is often inadequately addressed at the various stages of planning, designing and constructing LVSRs.

Environmental Issues

Many aspects of the geometric design process also have a potential impact on the physical and social/cultural environments, especially where the alignment traverses built-up areas and where there is a high potential for severe erosion. Unfortunately, various practical measures that can be undertaken during the geometric planning process to minimise environmental impacts are often not adequately understood and addressed.

From the above, it is apparent that existing design standards and practice are generally not appropriate for application in the SADC region. A need therefore exists to adapt these standards in order to provide acceptable levels of service, safety and uniformity consistent with the types of traffic generally experienced on LVSRs. Such adaptation needs to be based on local knowledge, experience, socio-economic conditions and established criteria within a design process that needs to be flexible and multi-faceted, from feasibility to the end-of-life cycle.

4.1.2 Basic Terminology

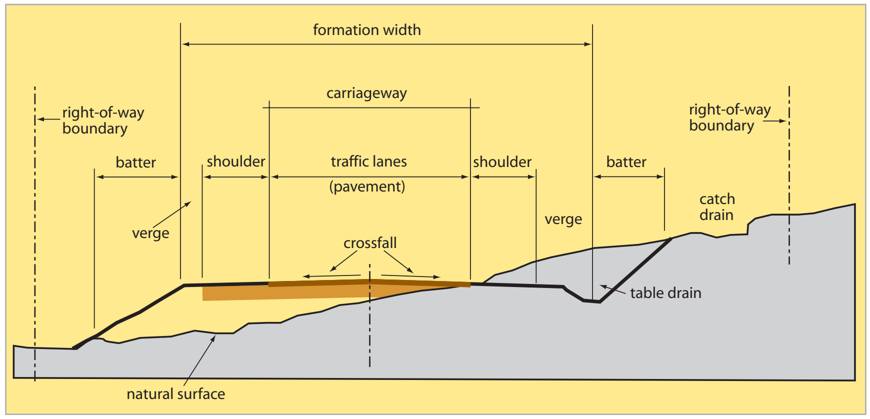


Figure 4.1 - Typical road cross section elements (after Austroads[2])

4.1.3 Purpose and Scope of Chapter

The main purpose of this chapter is to raise awareness of the widely differing recommendations made by various design guides or manuals pertaining to LVSRs. It highlights the many shortcomings that are inherent in those traditional approaches to geometric design that have been imported and used without appropriate adaptation to the specific characteristics of the LVSR environment. Particular emphasis is placed on the need to incorporate appropriate road safety features in the design process.

The approach adopted is not prescriptive; nor is it intended to be a detailed design manual that could supersede the need for application of sound principles by the knowledgeable design professional. Rather, it emphasises the need to consider the basis on which various design parameters are chosen in relation to the specifics of the SADC region's road environment.

4.2 Design Philosophy, Standards and Approach

4.2.1 Philosophy

The philosophy embodied in the geometric design of a road is linked to such factors as a country's economic prosperity, the state of development of the road network and the unique characteristics of the road environment within which the road functions. It would normally evolve from analytical evaluation and experience of local conditions and often reflect the physical and economic environment of the road project itself. Thus, geometric design philosophy would be expected to vary between industrialised and developing countries.

Flat terrain with little constraint on geometric standards.

The functionality and characteristics of the road network in the SADC region are quite different from those in industrialised countries. Not only are traffic levels relatively low, but the traffic mix is complex, consisting of a mixture of motorised and non-motorised traffic. The proportion of commercial vehicles and levels of pedestrianisation near peri-urban areas are also relatively high. This clearly dictates a need to develop a design philosophy and related standards that are suited to the socio-economic environment of the region. Such a philosophy would be expected to be quite different from that embodied in geometric design manuals developed in industrialised countries that often form the basis of geometric design in the region. Such manuals generally cater to higher traffic volumes, greater need for all-weather accessibility and provide for operational efficiency of the traffic using the network - requirements that are clearly less appropriate for the region.

Hilly terrain with constraints on geometric standards.

4.2.2 Standards

Geometric design standards provide the link between the cost of building and subsequently maintaining the road and the cost of its use by road users. Usually, the higher the geometric standard, the higher the construction cost and the lower the road user costs. The aim is to select design standards that minimise total transport costs. Thus, the relatively low traffic characteristics of LVSRs means that road improvements should be planned at the lowest practicable standards (without unduly impairing safety requirements) if costs are to be justified by the benefits obtained.

Unfortunately, there are no existing standards in any SADC country that are based on in-country research into economic and safety factors. Those standards that do exist vary tremendously, reflecting either the practice of the developed countries with which SADC countries have had previous ties or the preferences of international consultants who have worked in these countries. Many of them are a direct translation from overseas practice, sometimes with some modification to compensate for local operational differences and deficiencies, often without full evaluation of the consequences.

LVSRs, more than any others, call for a detailed examination of design options on the basis of sufficient data to allow an appropriate choice of geometric standards and should not be designed according to rigid guidelines and standards established a priori, often in environments very different from those prevailing in the SADC region.

In view of the above, until standards for LVSRs are developed, the challenge is to apply existing designs and standards in a flexible manner to fit the parameters pertaining to the local environment and to achieve safe economic design.

Choice of Standards

The choice of geometric design standards is related to the function of a road. In a developing region, such as the SADC, three stages of road network development usually occur, as follows:

- Stage 1 - provision of access
- Stage 2 - improvement in existing capacity
- Stage 3 - increase in operational efficiency

LVSRs generally fulfil a function within road networks at Stages 1 or 2 of the above sequence. Thus, the road design philosophy and standards should reflect the particular requirements of such roads and their particular characteristics. In this regard, a case may be made for a "relaxation" of traditional standards as, when sensibly applied, they can result in substantial construction cost savings, with little additional risk of increased accidents. Such relaxations, or local reductions in standards, can be undertaken in the context of the "Design Domain", a relatively new concept in geometric design which is described in Section 4.3.2.

4.2.3 Approach

Investment in road infrastructure represents a large part of investment in national development programmes. It is therefore even more important to ensure that scarce funds are deployed to best advantage. There is a tendency for the construction cost per kilometre to increase as each road design criterion is considered. As a matter of policy, therefore, it is necessary to ensure that an approach to geometric design is adopted which is appropriate to the prevailing socio-economic conditions. This may mean considering design approaches that favour labour exclusive rather than plant exclusive construction technology.

Box 4.1 - Labour-based methods and geometric design[3]

In a labour-abundant economy, it is often beneficial to employ labour-based rather than equipment-based methods of road construction. In such a situation, the choice of technology can be a major constraint or facilitator affecting design. Where labour-based technology is being contemplated at the geometric planning stage, it could have the following implications:

- the geometric standards that are achievable will be seriously affected, especially in rolling, hilly or mountainous terrain
- economic haul distances will be limited to those achievable using wheel barrows
- mass balancing will need to be achieved by transverse rather than longitudinal earthwork distribution
- maximum gradients will need to follow the natural terrain gradients
- horizontal alignments will need to be less direct
- maximum cuts and fills will need to be low

The reverse of the above is true for equipment intensive technology. Thus, at the geometric planning stage, consideration must be given to the type of technology to be employed in road construction and to the influence that this will have on the approach to geometric design.

The following aspects of geometric design require particular consideration from a policy perspective as they have a crucial bearing on the life-cycle costs of LVSR provision:

- Design standards
  - design speed
  - cross-sectional dimensions
  - safety measures
  - maximum gradient
  - horizontal curvature

In the final analysis, the wide variety of topographic, climatic, economic and social conditions will dictate the road geometry appropriate to a specific situation. The aim should be to establish a basic network of LVSRs by spreading limited resources to cover several road projects rather than building a smaller number of roads to a higher standard. In this way, funds saved by using cost-effective design standards can be used for other projects which would bring the best economic return on the investment.

Cost-effective geometric design can be achieved by identifying areas where road standards could be made more flexible and more responsive to environmental changes consonant with local knowledge, experience, socio-economic conditions and established criteria.

4.3 Design Framework and Process

4.3.1 Framework

LVSRs fulfil a variety of functions within diverse operational environments. Thus, designs need to cater for an array of different situations in which consideration must be given to all the inter-acting elements that affect the design process.

In order to help define the situations which are appropriate for a specific design application, it is useful to group them within a design framework as shown in Table 4.1.

Table 4.1 - Design Framework

Element	Range	Influence on design
Project type	▪ New ▪ Existing	▪ greater flexibility of choice but there are few new "greenfield" projects ▪ focus on upgrading/reconstruction projects which places constraints on designer's choice ▪ designer's choice often restricted by nature of existing developments and roadside environment
Area type	▪ Urban ▪ Peri-urban ▪ Rural	▪ wide range of operating characteristics, constraints and configurations which vary widely in terms of - range of uses - traffic volumes, speeds and mix - pedestrian activity ▪ need for producing appropriate matching designs
Functional classification	▪ Primary ▪ Secondary ▪ Tertiary/access	▪ identifies relative importance of mobility and access functions for road ▪ prescribes related minimum standards
Terrain type	▪ Flat ▪ Rolling ▪ Mountainous	▪ influences choice of alignment, design/operating speeds and standards ▪ impacts on drainage and maintenance requirements and also on environment
Design/ operating speed	▪ Low ▪ Medium ▪ High	▪ used to correlate various features of design ▪ ultimately determines construction, maintenance and road user costs
Traffic volumes, type and mix	▪ Low ▪ Medium ▪ High	▪ provides fundamental basis of design ▪ includes both motorised and non-motorised traffic

Physical obstacles in the terrain can constrain design options.

LVSR projects will be, predominantly, the upgrading of existing gravel roads to a bituminous standard. The designer's freedom of choice will often be restricted by developments, including ribbon development, surrounding the road to be upgraded. Thus, rigid adherence to standards may not be possible and flexibility must be built into the process through the adoption of flexible design techniques.

4.3.2 Process

The process of geometric design contains various stages within which the final product is gradually developed. The process is iterative. A number of investigations and evaluations have to be undertaken, questions asked, and decisions taken in preparatory phases that may have to be re-evaluated later, until the process has provided satisfactory results. An outline of the design process is presented in Figure 4.2.

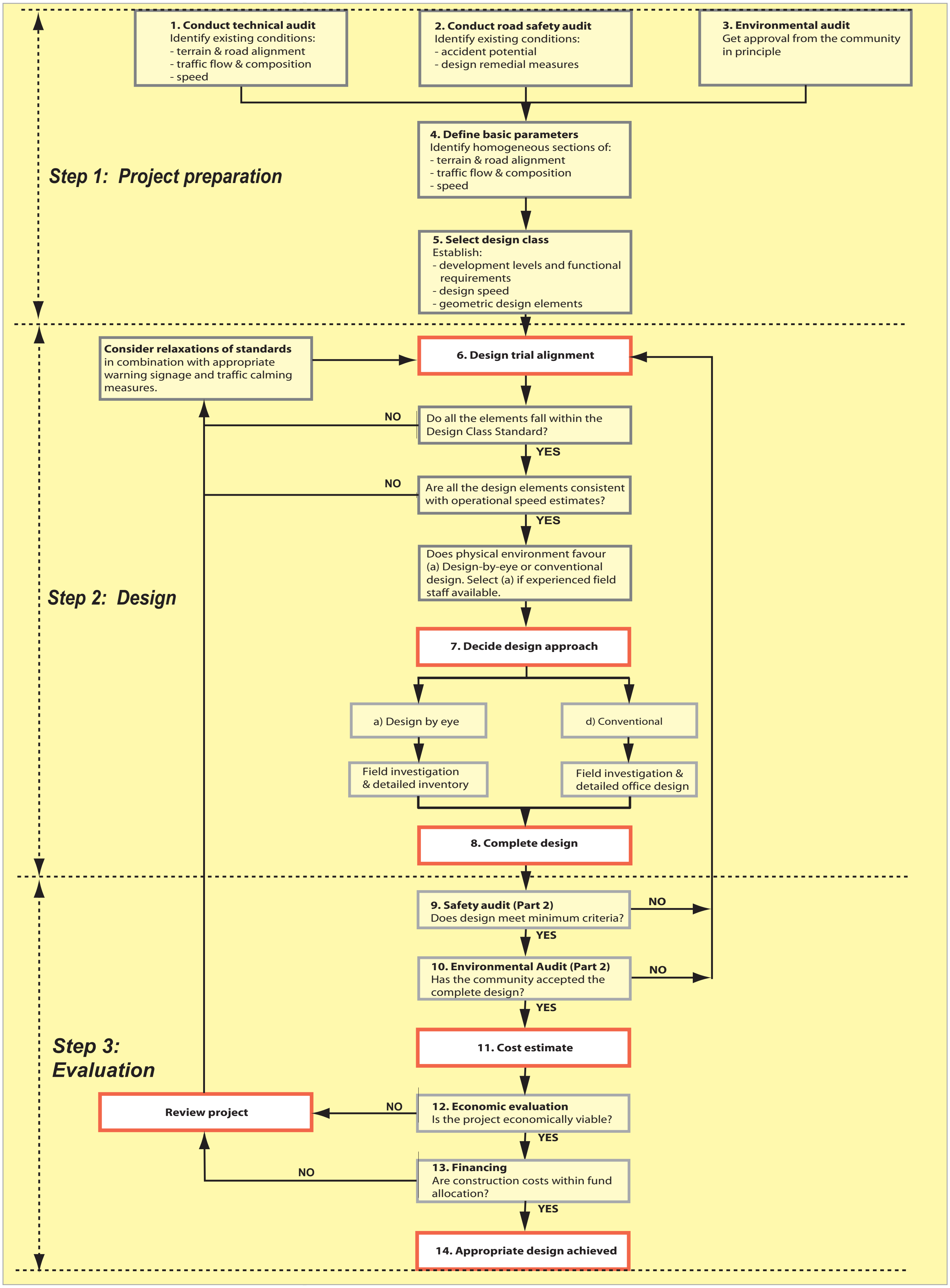


Figure 4.2 - The geometric design process

The design process may be broken down into three phases as follows:

- project preparation
- design
- evaluation

A. Step 1 – Project Preparation

The project preparation phase embodies a number of concepts that are not normally considered in conventional design manuals. These include a focus on the planning aspects of the geometric design process in which there is:

- a primary, over-riding focus on road safety
- continuous public involvement in all stages of the design process

The main activities undertaken in the project preparation phase include:

(1) ***Technical Audit:*** One of the first tasks to be carried out is a technical audit of the project. This entails information gathering on such factors as terrain and road alignment, traffic flows and composition, overall speed and speed over individual sections, land use and settlements including schools and hospitals. Traffic counts and traffic forecasts also need to be conducted. The results of the technical audit provide an input into the next step - the definition of basic parameters.

(2) ***Road Safety Audit (1):*** The preliminary design stage of the audit entails investigation of all factors that could have an adverse impact on the safety of the design, including such factors as accident "black spots" and the accident potential related to the improvement/upgrading of the road assessed, so that the information can be included in the subsequent design.

(3) ***Environmental Audit (1):*** The community should be consulted and involved at an early stage of the design process. This is necessary to ensure that their views are accommodated where appropriate and their priorities taken into account in the final design.

(4) ***Define Basic Parameters:*** The main task is to identify and group the project into homogenous sections with similar conditions and characteristics such as terrain, alignment, traffic, speed, land use and development. The information will form the basis for selection of the design class.

(5) ***Select Design Class:*** The selection of design speed and geometric elements is based on the developmental potential and functional requirements of the road. The design class for each homogenous section of road, in terms of terrain, road alignment, traffic and speed, can then be determined as a basis for selecting the various design elements.

B. Step 2 – Design

(6) ***Design Trial Alignment:*** The trial alignments will confirm if the intended standard can be introduced, for instance, if the design elements fall within the standard and are consistent with the expected operational speed. Failure to comply with set conditions will require new trials with modified inputs. Such trials may include relaxation of standards consisting of measures such as a lower design speed in combination with appropriate signage or traffic calming measures.

(7) Decide on design approach: The design approach will be dependent on topography, institutional arrangements, availability of suitable skilled and experienced field staff, etc. The selection of the design approach is also influenced by the type of project in terms of whether it involves rehabilitation of an existing facility or provision of a new one. The requirements for the field surveys and investigations will also depend on the type of project.

(8) Complete Design: The completion of the design concludes Stage 2 - Design, and is followed by the next Stage 3 - Evaluation. This stage includes the follow-up of a number of audits and evaluations related to safety, social considerations, costs, along with economics and financing which received preliminary consideration in the project preparation phase.

Step 3 – Evaluation

(9) Road Safety Audit (2): The design features are examined from a safety point of view. Remedial measures are proposed for possible weaknesses in the design. If the design is such that simple remedial measures are not adequate to rectify the shortcomings, the design will need to be reviewed and new trial alignments be carried out. This iterative procedure will be repeated until the design is acceptable from a road safety perspective.

(10) Environmental Audit (2): Public participation should continue after the detailed design is completed. If necessary, modifications or adjustments to the design, as a result of community consultations, will have to be undertaken to ensure that the final project accords with local requirements.

(11) Cost Estimate: Cost estimates should be conducted at various steps of the design process as they may influence the scope of the project and decisions made concerning the design controls and elements. A detailed cost estimate will be required at final design stage to allow an economic evaluation of the project to be carried out.

(12) Economic Evaluation: Cost-benefit analyses, as described in Chapter 3, need to be undertaken to allow the viability of the project to be assessed. If the project turns out to be not viable in terms of the criteria prescribed, modifications to the project may need to be undertaken. Such modifications may include relaxations of design standards, stage construction, or other factors that reduce cost or increase benefits.

(13) Financing: Adequate financing for the project, in terms of both construction and future maintenance costs, needs to be secured before implementation begins, otherwise the sustainability of the project could be jeopardised. Should such funding not be available, it may be preferable to defer implementation until it can be obtained.

(14) Appropriate Design Achieved: If the tasks outlined in the flow chart and in the discussion above have been methodically carried out, the final result should be an appropriate geometric design.

In 1990 road traffic accidents were rated ninth in the top ten causes of death and disability in the world. By 2020 it is predicted that it will be rated third.

Harvard School of Public Health Projections.

Unconventional signs are sometimes used to warn of the dangers of overloading and speeding.

A poorly-maintained road sign can be the cause of road accidents.

4.3.3 Safety Issues

Importance of Safety

Studies carried out by international organisations reveal that the road safety situation throughout the African continent, including the SADC region, is one of the worst in the world[4]. Fatality rates, in relation to vehicle fleets, are 30 - 40 times higher than those of industrialised countries. Indeed, in several countries a motor vehicle is over one hundred times more likely to be involved in a fatal crash than in Europe or the USA.

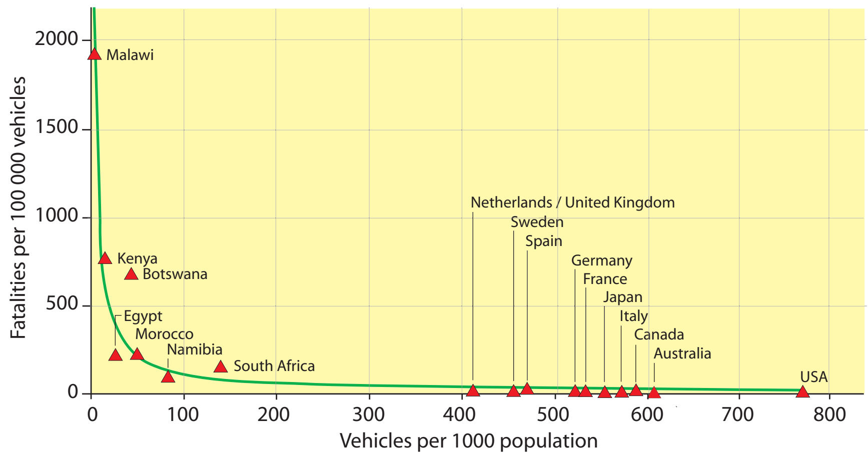


Figure 4.3 - International comparison of fatalities in selected countries[4]

Because of the substantial cost implications on the economies of these countries - of the order of one to two per cent of gross national product (GNP) - road safety has become of paramount importance in all aspects of road provision.

Road safety is multi-dimensional in nature and cannot be discussed in isolation from geometric design. As illustrated in Figure 4.4, the various elements of the road system, such as geometry and pavement condition and operational conditions, such as operating speed, influence road safety.

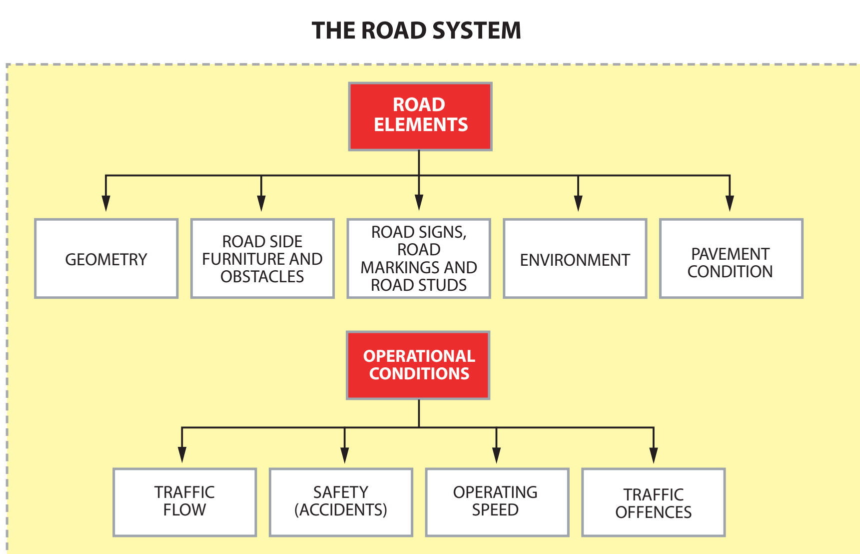


Figure 4.4 - Elements of the road system and operational conditions

For example, as illustrated in Figure 4.5, overloading has an important influence on pavement condition and deterioration and is influenced by police surveillance, while speeding is also influenced by the road geometry and police surveillance. Both overloading and speeding, in turn, have an influence on safety in terms of accidents.

Speed limit painted on the road.

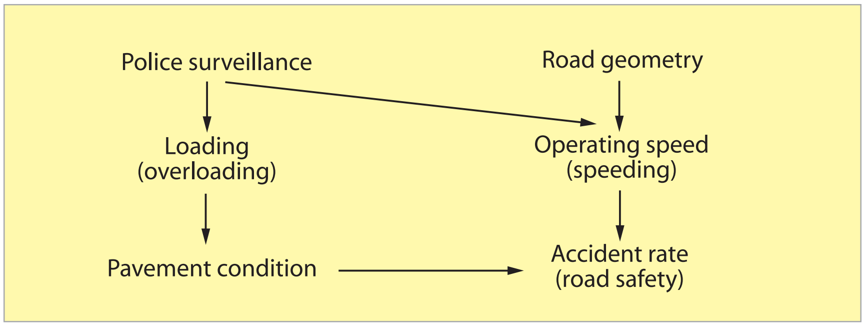
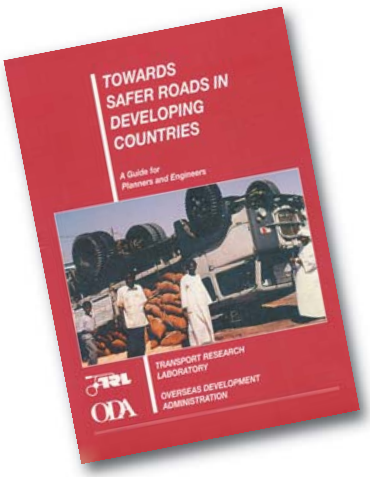


Figure 4.5 - An example of the interrelationship between road elements and operational conditions

Thus, although the importance of designing for safety is now widely recognised, the actual process of identifying key design features and resolving the conflict of safety and other considerations is complex and requires tackling in a holistic manner.

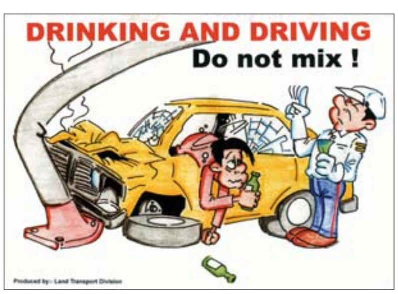


The above document provides practical guidance on how to make roads safer by highlighting the key, safety-related factors which need to be incorporated when planning, designing and operating road networks.

The Nature of Accidents

Confronting the challenge of safety requires proactive strategies that treat the root causes of accidents and levels of severity before they occur. To this end, valuable guidance on accident prevention is given in a number of documents including, particularly, the TRL guide entitled *Towards Safer Roads in Developing Countries*[5].

As illustrated in Figure 4.6, accidents are multi-causal in nature, involving human factors, the road environment and vehicle factors. They are more often caused by a *combination* of these factors, with human factors contributing to an estimated 95 per cent of all accidents, the road environment 28 per cent and vehicles 'only' 8 per cent. Thus, although not the dominant cause of road accidents, it is important that features are not introduced in the geometric design which could result in additional negative impacts on road safety.



Drinking and driving are a common cause of accidents in the SADC region.

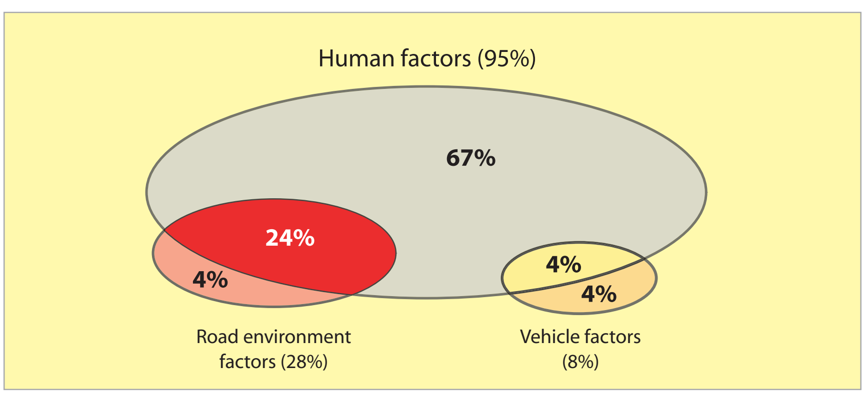


Figure 4.6 - Factors contributing to road accidents[6]

The Influence of Design

Almost all geometric design elements affect road safety by:

- influencing the ability of the driver to control his/her vehicle
- influencing the opportunities that exist for conflict (and accidents) with other road users
- influencing the outcome of an out-of-control vehicle
- affecting the behaviour and attentiveness of a driver

Reviews of road projects in many developing countries reveal a depressing catalogue of unsafe and inconsiderate road designs which though compliant with highway design standards, remain unsafe because of the particular characteristics of the traffic using the road and the "operating environment" in which the road will function[4].

Thus, by incorporating good design principles from the start of the design process, it is possible to avoid many problems simply by planning and designing new roads or upgrading existing ones in a safety conscious manner. *Moreover, it is often possible to improve road safety characteristics markedly at little or no extra cost, provided the road safety implications of design features are considered at the design stage. Unfortunately, road design engineers are often part of the problem and their failure to take adequate account of operational use of roads often result in increased speeds and increased deaths when such roads pass through communities straddling the road.*

There are a number of tools to assist in this process, such as Road Safety Audits, which are considered below.

Designs need to cater for different types of road users.

Box 4.2 - Key principles for designing safer roads

Adherence to various key principles of design can considerably improve the safety of LVSRs. These key principles are summarised below:

- *Designing for all road users.*
  - includes non-motorised vehicles, pedestrians, etc.
  - has implications for almost all aspects of road design, including carriageway width, shoulder design, side slopes and side drains
- *Providing a clear and consistent message to the driver.*
  - roads should be easily "read" and understood by drivers and should not present them with any sudden surprises
- *Encouraging appropriate speeds and behaviour by design.*
  - traffic speed can be influenced by altering the "look" of the road, for example by providing clear visual clues such as changing the shoulder treatment or installing prominent signing
- *Reducing conflicts.*
  - cannot be avoided entirely but can be reduced by design, e.g. by staggering junctions or by using guard rails to channel pedestrians to safer crossing points
- *Creating a forgiving road environment.*
  - forgives a driver's mistakes or vehicle failure, to the extent that this is possible, without significantly increasing costs
  - ensures that demands are not placed upon the driver which are beyond his or her ability to manage

Despite adherence to various key principles for designing safer roads, very few engineering measures, on their own, are totally self-enforcing. They normally require other measures of external control and facilitation such as enforcement and education, to be fully effective (ref. Section 4.5).

Road safety audits help to produce designs that reduce risks to road users.

Road Safety Audits

Safety should be given special attention at all stages of the design process. One effective means of achieving that goal is by the use of a road safety audit. This may be defined as "*…a formalised examination of an existing or future road or traffic project or any project which interacts with road users, in which independent, qualified examiner reports on the project's accident potential and safety performance*"[6].

The objectives of a road safety audit are essentially to:

- identify and report on the accident potential and safety problems of a road project
- ensure that road elements with an accident potential are removed or improved
- ensure that measures are implemented to reduce accident risks

As illustrated in Figure 4.7, road safety auditing is an iterative process and should be carried out at all stages of a road project from preliminary design, through detailed design to pre-opening. It provides an opportunity, especially during the preliminary design stages of the project, to eliminate, as far as possible, road safety problems in the provision of both new roads as well as those being upgraded.

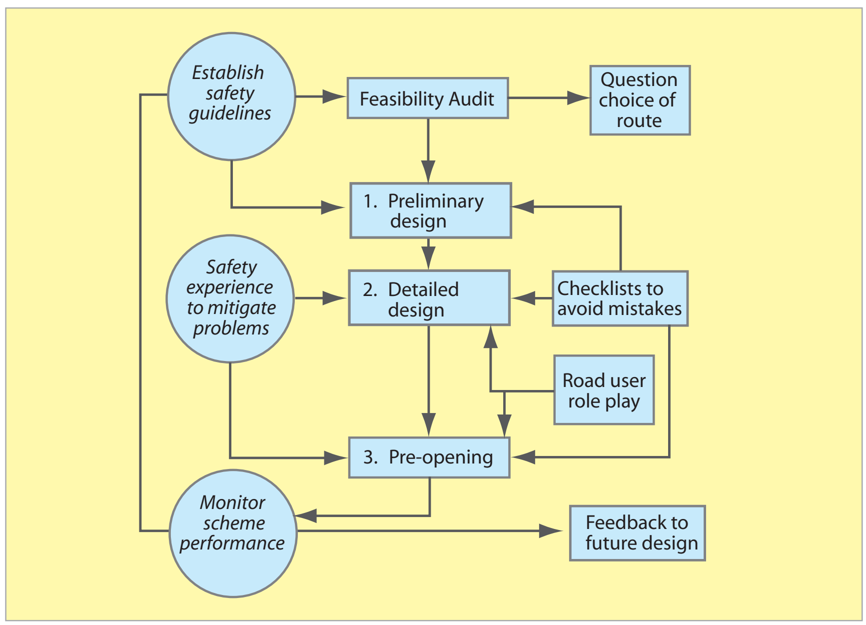


Figure 4.7 - Road safety audit flow-chart

The major benefits of such audits include:

- a reduction in the likelihood of accidents on the road network
- a reduction in the severity of accidents on the road network
- an increased awareness of safe design practices among traffic engineers and road designers
- a reduction in expenditure on remedial measures
- a reduction in the life-cycle cost of a road

The resources required for carrying out a road safety audit are usually quite small and could add about 4 per cent to the road design costs. However, the benefits can be very marked with an estimated potential benefit-cost ratio of 20:1[7].

By conducting road safety audits, a road authority is showing that it has the intention to improve the safety on its roads, and consequently has a stronger defence against tort liability claims.

Box 4.3 - Road Safety Audits in SADC

Road safety audits have not yet become a formalized, mandatory aspect of the road design process in many SADC countries. At present, road safety is assumed to be addressed through adherence to geometric design standards. However, this is neither adequate nor sufficient. It has been shown that *"roads designed to standards are neither necessarily safe nor unsafe and that the linkage between standards and safety is largely unpremeditated"* [8]. As a result:

- there is a need to accelerate the rate of adoption of a more formalized road safety audit procedure appropriate to all roads in any country
- road safety audit procedures should be introduced as part of a comprehensive road safety programme in all countries
- lessons learned from safety audits should be centrally coordinated and shared amongst all countries in the region

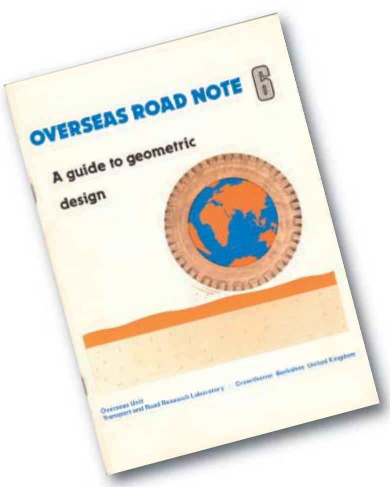
Designs should cater for pedestrians as well as vehicular traffic.

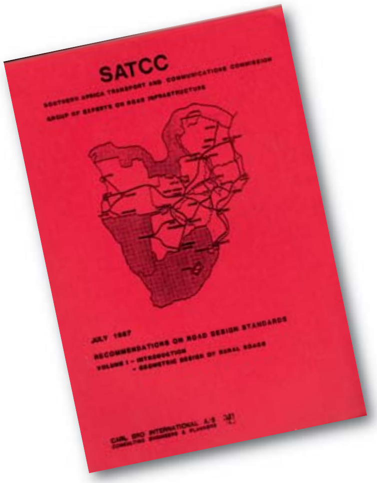
4.3.4 Design Guides/Manuals

In recognition of the shortcomings of the use of guides from developed countries for LVSRs, attempts have been made to develop more appropriate guides for developing countries (e.g. TRL's ORN 6[9]). Recourse has also been made to the use of more appropriate standards emanating from other countries such as Australia (e.g. NAASRA[10], Austroads[11] and ARRB[12] guidelines). Most recently, guidelines have been developed in the region for use either nationally (e.g. South Africa's G2 Manual[8]) or regionally (e.g. SATCC's Geometric Design of Rural Roads[13]). However, neither of these guidelines apply to LVSRs. Table 4.2 provides a listing of the various design guides and the extent of their use in the region.

Table 4.2 - Design guides/manuals used in SADC region

Design Guide/Manual	Degree of Use		
	High	Med	Low
USA			
• AASHO:			
- A Policy on Geometric Design of Rural Highways (1965).	X		
• AASHTO:			
- A policy on Geometric Design of Highways and Streets (1984).	X		
- Guidelines for Geometric Design of Very Low-volume Local Roads (ADT ≤ 400) (2001).			X*
Australia			
• NAASRA:			
- Interim Guide to the geometric design of rural roads. (1980).		X	
• Austroads:			
- Rural Road Design: Guide to the design of Rural Roads (1989).		X	
• ARRB:			
- Road classifications, geometric designs and maintenance standards for low-volume roads (2001).			X*
United Kingdom			
• TRL:			
- Overseas Road Note 6: A guide to geometric design (1988).		X	





Southern Africa			
• SATCC: - Recommendations on Road Design Standards: Geometric Design of Rural Roads (1987).		X	
• South Africa: - G2 - Geometric Design Manual (South Africa, 2003).			X
• Member states: Country manuals based essentially on one or other of the guides listed above.	X		

* These guidelines have very recently been developed and knowledge of their existence and use is still very limited.

All the guidelines/manuals listed above are based on different philosophies and make different assumptions or use different criteria for developing design values for the various design elements. For example, some guides give emphasis to safety considerations while others may place emphasis on service level, capacity, comfort or aesthetic values. Not surprisingly, the resulting design values recommended, and their related cost implications, all differ, sometimes quite significantly. Thus, it is essential for the designer to have a thorough understanding of the origin, background and basis of development of the design guides or manuals and related design criteria as a basis for adaptation, where necessary, and subsequent judicious application to LVSR situations.

In the next section, a comparison is made of design values obtained from the application of some of the design guides considered most appropriate for use in the SADC region.

4.4 Design Controls and Elements

4.4.1 Techniques

There are a number of techniques that have been developed in recent years which offer a considerable degree of *flexibility* to the LVSR designer in the design process as well as improve the quality of the design. These are described briefly below:

Context Sensitive Design

Context Sensitive Design[14] is responsive to, or consistent with, the road's natural characteristics and human behaviour, i.e. the design can deviate when necessary from accepted design criteria. Consideration is given to the desires and needs of the community by inviting the appropriate stakeholders to participate in identifying solutions so that they are acceptable to the community.

Context Sensitive Design recognises that exceptions may be required in some cases in applying standards. For example, where provision of an engineered alignment results in excessive earthworks, it may be preferable to lower the design speed in order to minimise social or environmental impacts.

Design Domain Concept

The 'design domain' concept[8], shown in Figure 4.8, recognizes that there is a range of values which could be adopted for a particular design parameter within absolute upper and lower limits. Values adopted for a particular design parameter within the design domain would achieve an acceptable, though varying, level of service in average conditions in terms of safety, operational, economic and environmental consequences.

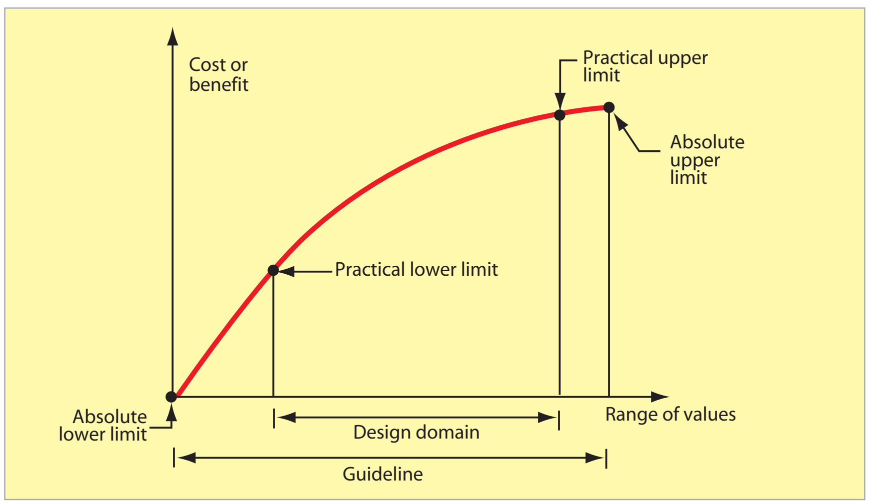


Figure 4.8 - The design domain concept

While values within the lower region of the design domain are generally less safe and less operationally efficient, they are normally less costly than those in the upper region. In the upper region of the domain, resulting designs are generally safer and more efficient in operation, but may cost more to construct. The design domain sets the limit within which parameters should be selected for consideration within the value-engineering concept.

The flexibility offered by the Design Domain concept

For many elements, a range of dimesions is given and the designer has the responsibility of choosing the appropriate value for a particular application. If a design involves compromise, it may be more appropriate to compromise several elements by a small amount than to compromise one element excessively. It is important that a design should be balanced.

The design domain concept provides the following benefits to the designer:

- It is directly related to the true nature of the road design function and process, since it places emphasis on developing appropriate and cost-effective designs, rather than simply meeting standards.
- It directly reflects the continuous nature of the relationship between service, cost and safety and changes in design dimensions. It thus reinforces the need to consider the impacts of 'trade-offs' throughout the domain and not just when a "standards" threshold has been crossed.
- It provides an implicit link to the concept of 'Factor of Safety' - a concept that is used in other civil engineering design processes where risk and safety are important.

An example of the design domain concept for shoulder width is shown in Figure 4.9

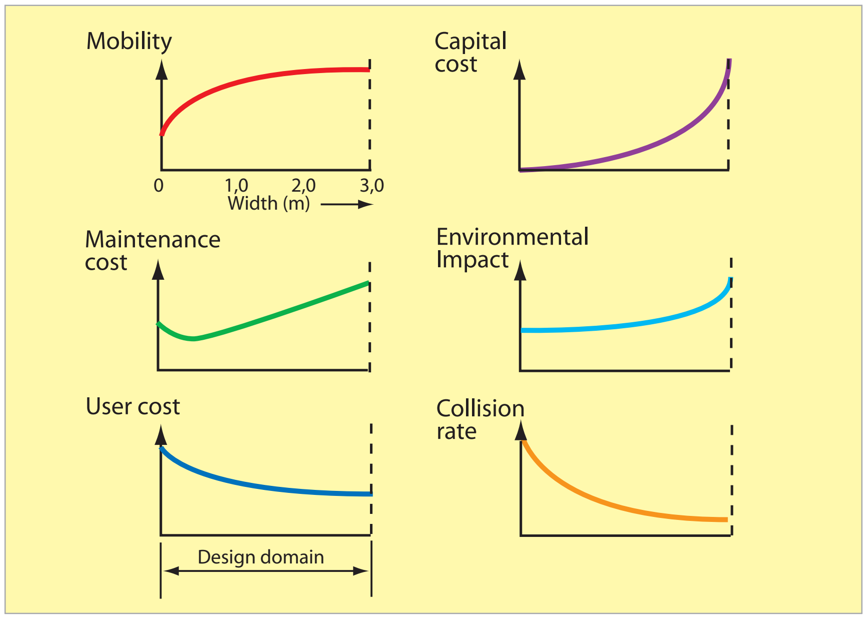


Figure 4.9 - Example of design domain application - shoulder width[14]

Design-By-Eye

Conventional approaches to design involve precise engineering surveys over the total length of the road as a basis for producing horizontal and vertical alignments and cross-sections on working drawings from which quantities are normally calculated. The cost of this approach, which is normally justified for relatively high-volume/standard roads, can hardly be justified for relatively low-volume/standard roads.

Design-by-eye is a relatively simple approach to design which is intended primarily for the upgrading of existing LVRs where the geometry is adequate. In this approach, the route alignment is chosen "by eye" at the time of construction by experienced site staff who are aware of the economic, operational and safety consequences of geometric design.

Box 4.4 - Advantages of the Design-by-eye approach

- Enables the engineer to fit the alignment to the terrain so that it causes minimum disturbance to any existing facilities and the adjacent physical environment.
- Obviates the need for a conventional topographic survey of the existing road and normal plan and profile drawings do not need to be prepared.
- Allows the geometry of the road to be described on a simple road location straight-line plan showing roughly the horizontal alignment with kilometre-stationing and possible improvements indicated, such as sight distances.
- Minimises earthworks, increases speed of construction and reduces preparatory costs and, ultimately, construction costs by 10 - 20 per cent.
- Can result in a finished product of at least similar quality to the conventional approach.

The design-by-eye approach is best suited to situations where detailed documentation in terms of drawings and quantities is not required. This includes situations where construction is undertaken by a management team or by in-house construction units rather than by a contractor governed by rigidly specified contractual and payment conditions of a contract.

The degree to which the design-by-eye approach is applied in relation to conventional approaches (full horizontal and vertical survey and control) can also vary widely depending on local circumstances and can include the following options:

- no survey, but brief indications of corridor, areas to avoid, required fill/cut heights for drainage, soils, or other information
- survey of the horizontal alignment and/or vertical alignment with spot surveys of alignment options at critical locations
- survey of the horizontal alignment and vertical alignment up to e.g. sub-base level only. Base course then to be placed within thickness tolerances

4.4.2 Controls

The need to relate the physical elements of a road with the requirements of the driver in an environmentally acceptable manner imposes a number of controls on the road designer. Many of these controls relate to the characteristics of the road environment; those that may be appropriate for one environment may well not be appropriate for another. The more important design controls include:

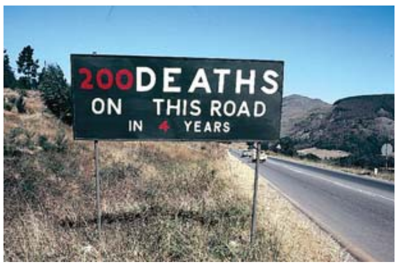
- driver characteristics
- design speed
- sight distances
- design traffic
- design vehicles
- environmental factors

Design parameters such as driver-eye-height and perception-reaction time vary considerably among drivers as well as vehicle type and driving conditions. Thus, in relation to the underlying assumptions made, guidance on various design parameters pertaining to driver characteristics vary quite significantly as illustrated in Table 4.3. As a result, the values derived for related design elements such as sight distance are affected. Such guidance should be carefully evaluated in relation to the assumptions made and their applicability to the project situation.

Table 4.3 - Driver characteristics recommended for rural/low-volume roads

Parameter	Design Guide		
	SATCC	TRL ORN6	ARRB
Driver eye height (m)	1.00	1.05	1.15
Brake reaction time (secs)	2.50	2.00	2.50
Object height (stopping) (m)	0.10	0.20	0.20
Object height (passing)(m)	1.00	1.05	-

Speed Kills – Kill Speed



Non-standard sign intended to shock drivers into driving carefully.

Design Speed

The *design speed* is probably the most influential factor affecting the geometric design of a LVSR and is influenced by the following factors:

- nature of the terrain
- classification of the road
- density and character of the adjoining land use
- traffic volumes and composition expected on the road
- cross-section

Design speed is normally taken as the maximum speed that 85% of the drivers are expected to adopt over a specified section of the completed road when conditions are so favourable that the design features of the road govern the driver's choice of speed. The higher the design speed, the higher, usually, the cost of construction. In undulating country, a rough rule of thumb is that an increase of 20 km/h in the speed standard doubles the cost of earthworks.

It is noteworthy that the conventional design speed approach to specifying alignment design standards carries implicit assumptions regarding driver behaviour which have not been substantiated by empirical research[15]. Alternative design procedures have been developed which ensure compatibility between alignment standard and observed driver-speed behaviour, and in which emphasis is placed on consistency and driver expectancy rather than absolute minimum standards. Such an approach is believed to result in safer operations, particularly for low-standard alignments, than the conventional design speed approach[16]. As a result, it would appear better suited to the SADC region where driver behaviour is a critical determinant of operational, and hence, design speed.

"The expertise required by the low-volume road designer may lie in his ability to make his intentions clear to the road user and to create a state of mind in the driver such that he will be content to travel at safe speed". However, while the approach is sound, quantitative guidelines are still lacking.

Although speed has been viewed traditionally as the most influential factor affecting the geometric design of LVSRs, it is also suggested that life-cycle costs could be considered as the most important factor[3]. The rationale behind this approach is that cost will continue to be the most critical constraint on LVSR provision. This cost minimisation approach also applies to the horizontal and vertical design (4.4.3 Elements). Speed, geometrics etc. would then emerge as the outputs from the life-cycle costs analysis.

Speed limits can be used to influence driver behaviour, but only if they are realistic. When the speed limit is set at a level that is significantly different from the 85th percentile of the free speed, this tends to produce an accident prone situation as drivers tend not to adjust their speeds to the notional classification of the road but, rather, to its physical characteristics. Attention should therefore be given to creating a road environment which tailors the operating speed to a level commensurate with the constrained alignment[17].

Box 4.5 - Design versus operational speeds in the SADC region

There are marked differences in the physical environments of countries in the SADC region which, as a result, have a large influence on the application of a number of geometric parameters. For example, the terrain in countries such as Botswana and Namibia is mostly flat. As a result, operational speeds tend to be much higher than the design speed and, *from a traffic safety perspective, there may be need to introduce special measures to constrain the high operational speed close to the design speed*. In contrast, in countries such as Lesotho, Seychelles and Mozambique, the terrain in parts is very mountainous. As a result, the design features of the road govern and sometimes constrain the driver's selection of speed.

Braking distance and those factors which depend on it, such as sight distance, are approximately proportional to the square of the speed and every increase in the design speed represents a significant increase in the value of these factors. However, extra construction costs are usually offset by the benefits to traffic, namely increased safety, capacity and convenience, and lower road user costs.

Guidance on design speeds is given in a number of design manuals [8,9,10,11,12,13] which all purport to apply to rural/LVRs in developing countries. The design speeds recommended vary, presumably depending on the philosophy of design adopted and the environment for which they are meant to apply - examples are shown in Table 4.4. In view of the critical effect that design speed has on the values of other geometric elements and the related costs of implementing them, careful consideration should be given to the choice of this influential parameter.

Table 4.4 - Recommended design speed values for selected design guides

Parameter	Design Guide								
	SATCC			TRL ORN 6			ARRB		
Traffic (ADT)	-			100 - 400			>100		
Terrain	F	R	M	F	R	M	F	R	M
Design Speed km/h	70	70	50	70	60	50	80	70	50

Note: F = flat, R = rolling, M = mountainous.

Design Vehicle

The physical characteristics of vehicles and the proportions of the various sizes of vehicles using a road are positive controls in design and define several geometric design elements. The dimensions used to define design vehicles are typically the 85th percentile value of any given dimension but are, in fact, hypothetical vehicles selected to represent a particular vehicle class.

The dimensions of design vehicles adopted in design manuals developed overseas are, quite naturally, based on vehicle types found in those countries. However, the range of vehicle types found in the SADC region and their operating characteristics, in terms of vehicle performance, condition, usage, traffic mix and road users' attitude, vary quite significantly from those in developed countries. Thus, careful attention should be paid to design vehicle characteristics in the LVSR design process.

Vehicle size regulations in the region have undergone substantial revisions in recent years which have resulted in the emergence of relatively large, multi-vehicle combinations up to 22 metres in length. These developments also indicate the need to adopt design vehicles that are appropriate to the region.

Designs need to accommodate expected traffic over the life of the road.

Design Traffic

The *design traffic* is a critical design control which has a major impact on all geometric design elements of a road. For HVR's, this factor normally applies only to motorised traffic in terms of Annual Average Daily Traffic (AADT) in the *design year*. However, for LVSRs, due account must also be taken of non-motorised traffic, animal-drawn vehicles and large pedestrian flows near urban and peri-urban areas which all affect such design elements as carriageway and shoulder widths. Unfortunately, none of the recent regional guidelines and few international guidelines, fully cater for non-motorised traffic. Measures that could be considered are wider shoulders, sealed shoulders, wider side drains or physical separation from motorised traffic, all of which will increase costs.

Good sight distances on a well-designed LVSR. Note wide shoulder and shallow slope to drainage ditch which both reduce potential hazards.

Sight Distance

A critical feature of safe road geometry is provision of adequate sight distance – the distance ahead that can be seen by the driver. As an irreducible minimum, drivers must be able to see objects on the road with sufficient time to allow them to manoeuvre around them or to stop. The basic elements of sight distance which are important to LVRs include:

- stopping sight distance - the distance needed for safe stopping from travelling speed
- meeting sight distance - the distance needed for drivers of two vehicles travelling in opposite directions to bring their vehicles to a safe stop
- passing sight distance - the distance needed to see ahead for safe overtaking

The values of Stopping Sight Distance (SSD) and Passing Sight Distance (PSD) recommended in various design manuals for rural/LVRs vary quite significantly as shown in Table 4.5. For SSD, this is due to different assumptions regarding brake reaction time and braking distance, which is dependent on vehicle condition and characteristics and object size. For PSD, this is due to different assumptions about the component distances in which a passing manoeuvre can be divided, different assumed speeds for the manoeuvre and, to some extent, driver behaviour.

Table 4.5 - Minimum stopping (SSD) and passing (PSD) sight distances

Design Speed (km/h)	SATTC		TRL ORN6		ARRB	
	SSD	PSD	SSD	PSD	SSD	PSD
40	44	110	35	-	-	-
50	-	-	50	140	50	-
60	79	230	65	180	-	-
70	-	-	85	240	90	-
80	126	420	-	-	110	-
100	185	700	160	430	-	-

Deep V-type drainage ditches leave no room for recovery if a vehicle runs off the road.

Sight distance has an impact on road safety. Poor visibility alone may cause a collision between oncoming vehicles. No local guide is available for LVSRs. In the final analysis, therefore, the designer should be aware of the differences in sight distance recommended by various guides and should adopt values for which the underlying assumptions accord closest to project conditions.

Bio-engineering offers the engineer a new set of tools, but does not normally replace the use of civil engineering structures. The materials and skills are all available in rural areas, however remote.

Environmental Issues

All road projects have an impact on the environment. However, the provision of LVSRs that result in an improvement of existing earth/gravel roads without involving major earthworks or disturbance of existing cut and fill slopes or drainage patterns have little or no environmental impact. Indeed, the introduction of a sealed road as a replacement for an earth/gravel road has an important positive effect on the environment in that there is no longer any dust from the earth/gravel road which would have had a negative impact on the environment, particularly when the road passed through built up areas.

When there is a new road alignment or when spot improvements include excavations in existing slopes, the environmental impacts of the works should be evaluated and suitable remedial measures introduced. Where slope instability or erodible soils present a problem, various remedial measures need to be considered, including bio-engineering methods, sometimes in combination with engineering structures. Such measures can also be used to improve surface drainage, particularly in rolling and hilly terrain with steep gradients.

Because of the low levels of traffic on LVSRs, environmental pollution from these roads is also low. However, there may be some slight increase in air pollution from increased emissions if steeper grades and super-elevations result from a design-by-eye approach. The disturbance due to noise is also increased in hilly areas where the strain on the engines due to steep gradients and heavy loads is extensive. Because of the low traffic volumes on LVSRs, the environmental impacts from emissions and noise are rather limited, but an environmental impact assessment should always be carried out.

In order to minimise the adverse impacts of LVSR provision, it is important to carry out an environmental audit at the commencement of the design process. Such an activity aims to:

- design road corridors to minimise environmental and social/cultural impacts and maximise user safety
- integrate the results of the geometric planning process into the design process
- identify appropriate design options to minimise impacts of the proposal and be compliant with the design brief
- provide an Environmental Design Report that sets out various criteria for minimising environmental impacts
- consider the objectives of all road users, and the natural and cultural values of the community through consultation
- minimise disturbance to the natural vegetation and landscapes
- ensure road drainage systems use natural drainage lines and maintain catchment integrity at all times

Lay-bys provide a safe haven where vehicles can pull off the road.

4.4.3 Elements

The road design process includes the selection, sizing and linking of the following elements which, to a large extent, is influenced by the chosen design speed:

- cross-section
- bridges and culverts
- horizontal alignment
- vertical alignment

All of the above elements affect road safety by influencing the ability of the driver to maintain vehicle control and identify hazards. It is therefore essential that particular attention should be given to safety as a prime design criterion.

Cross-Section

The following elements of the road cross-section for various classes of LVSRs need to be considered:

- width of carriageway
- width of shoulders
- cross-fall
- width of road reserve

A segregated footpath can be a cost-effective means of catering for high volumes of pedestrian traffic.

Of particular importance to LVSRs is the issue of catering simultaneously for the requirements of motorised as well as non-motorised traffic and pedestrians. In such circumstances, it will be necessary to consider cost-effective ways of segregating these various types of road users within an appropriately designed cross-section in which carriageway and shoulder widths play a crucial role.

Relatively wide shoulders (typically 1.5 to 2 metres) are particularly important in mixed traffic situations and serve the following important functions:

- movement of pedestrians and non-motorised traffic with minimum encroachment on the carriageway
- provision of additional manoeuvring space for vehicles and on which a driver may regain control of his vehicle if it goes out of control
- provision of space for the use of vehicles which are broken down
- provision of additional width to the cross section thereby improving sight distances

Where a segregated footpath is not possible, the use of relatively wide, sealed shoulders provides an acceptable surface for walking or cycling.

Examples and comments on appropriate values for the cross section elements for various classes of LVSRs are given in Table 4.6.

Severe edge break on a 5.0 m carriageway even at relatively low traffic levels (< 100 vpd).

A segregated footway on a narrow bridge provides protection for pedestrians.

Table 4.6 - Examples of typical cross-sectional widths[9]

Road Function	Indicative Traffic Flow (vpd)	Carriageway		Shoulder	
		Width (m)	Comments	Width (m)	Comments
Primary	> 400	6.0 to 7.0	Two commercial vehicles will pass completely within the carriageway; some movement towards the edge may occur.	1.0	Represents the minmum width recommended. Need to provide edge markings on shoulder. Widths may need to be increased to cater for pedestrians or non-motorised traffic. For traffic safety reasons, sealing of shoulders is recommended. This is also advantageous for structural and maintenance reasons.
Secondary	100 - 400	5.5 to 6.0	Need to maintain a minimum width of 5.5 m to avoid severe edge break even at low traffic levels.	1.0	
Tertiary/ Access	20 -100	3.0	Single lane. Two commercial vehicles will pass completely within the total width of 6.0 m utilising the shoulders.	1.5	

Note: In case of a high percentage of heavy vehicles, say over 40%, it is advisable to increase the carriageway to 5.5, 6.0 or 6.5 metres.

Higher standards will put a higher demand on the construction and maintenance budget and this needs to be considered at the design stage. For instance, increased road width produces a greater area to be maintained, thus increasing costs. However, increased width also spreads the traffic loading over a greater area, thereby to some extent reducing pavement deterioration. Thus, as described in Chapter 3, a life-cycle cost analysis of the various options should be undertaken to provide guidance on the optimum solution.

Camber and cross-fall: A commonly recommended value of all design manuals for the minimum normal cross fall on a paved road is 3%, including shoulders where they have the same surface as the carriageway. The preferable maximum value of super-elevation is normally set at 6 - 7% and with an absolute maximum of 10%. As indicated in Table 4.7, the use of a higher value of super-elevation makes it possible to introduce a smaller horizontal curve based on the same design speed.

Table 4.7 - Design radii for different super-elevations

Design speed (km/h)	Horizontal radius (m) (Super-elevation 6 %)	Horizontal radius (m) (Super-elevation 10%)
60	100	85

Bridges and Culverts

The cross-section on bridges needs additional consideration, particularly where they have been built with a restricted carriageway width. In such situations, there may be insufficient clearance for a truck to pass a pedestrian safely. This engenders a need to provide a segregated footpath and, where this is not possible, to employ traffic calming measures in combination with warning signs.

Horizontal Alignment

The following horizontal alignment elements need to be considered for various classes of LVSRs:

- minimum radius of curvature
- minimum stopping sight distance
- minimum passing sight distance
- super-elevation
- widening of curves

In general, the horizontal alignment should conform to the landscape. On new alignments, long straights should be avoided as they have an adverse impact on the motorist. Measures are required to reduce headlight or sun glare in appropriate circumstances, as well as to reduce boredom and fatigue.

Good combination of curves and adequate horizontal curvature provide for a safe road environment. However, a lack of road markings constitutes a serious safety hazard.

On existing alignments, as far as possible, upgrading should be undertaken without changing the existing curve geometry and cross-section. Curve improvements should focus on low-cost measures designed to control speeds, enhance curve tracking or mitigate roadside encroachment severity.

Minimum horizontal curvature is governed by maximum acceptable levels of lateral and vertical acceleration, minimum sight distances required for safe stopping and passing manoeuvres and values of side friction assumed for the road surface type. These design parameters are, in turn, related to the vehicle speeds assumed in the design. Curvature standards are thus explicitly or implicitly dependent on a number of assumptions which, as illustrated in Table 4.8, result in quite different values of minimum horizontal radii. The choice of minimum radius of horizontal curves has a significant impact on earthworks and costs and therefore needs additional consideration in LVSR design.

Table 4.8 - Comparison of minimum radii of horizontal curvature

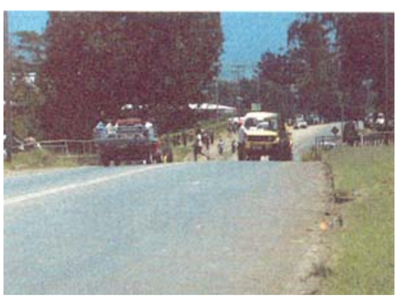
Design Speed (km/h)	Minimum radius of horizontal curvatures (m)							
	SATTC			TRL ORN6			ARRB	
	Side f	e=10	e= 6	Side f	e = 10	e = 6	Side f	e=7-10
40	-	-	-	0.30	30	35	-	-
50	-	-	-	0.25	60	65	0.35	45
60	-	110	140	0.23	85	100	-	-
70	-	-	-	0.20	130	150	0.31	100
80	-	210	250	0.19	175	200	0.26	160
100	-	350	420	0.15	320	375	-	-

F = side friction, e = super-elevation

Vertical Alignment

The main components of the vertical alignment include:

- maximum gradient
- minimum stopping or passing sight distances on crest curves
- minimum radius of crest and sag curves



Poor visibility due to hidden sag curve - a potential cause of accidents.

Vertical alignment has a direct effect on construction costs and depends on terrain. Cost can be reduced by reducing earthworks through careful route selection. Greater maximum grades should be considered for lower standard roads than for those with a higher classification. The benefits gained from reducing vehicle operating costs and time costs are unlikely to offset the additional construction costs of implementing minimal grades.

Table 4.9 shows the values for vertical crest and sag curves recommended by different design manuals for rural/LVRs in developing countries. As indicated in the Table, there is a considerable difference between the values recommended for both vertical crest and vertical sag curves, largely because of the different assumptions made in their derivation. The values recommended in the SATTC guide for trunk roads are based on headlight illumination criteria while the values by TRL ORN6 and ARRB are based on driver comfort criteria. In the SADC region, LVSRs serve a number of different functions and in very different terrains. In the absence of a local guide for LVSRs, the designer will need to determine which of the recommended values are most suited to the local terrain and road function (primary, secondary or tertiary).

The 'K' valued for a vertical curve is defined as the length of vertical curve in metres for a 1% change in grade.

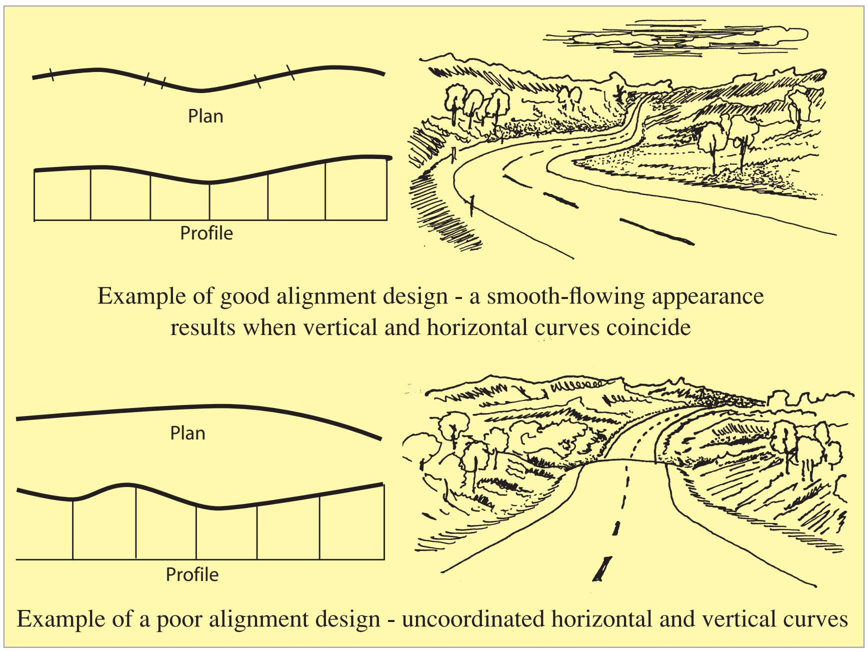
Table 4.9 - Comparison of minimum values of 'K' for vertical curves

Design speed (km/h)	SATTC		TRL ORN6		ARRB	
	Crest curves[1]	Sag curves[2]	Crest curves[1]	Sag curves[3]	Crest curves[1]	Sag curves[3]
40	6	8	3	1.3	-	-
50	11	12	5	2.2	5	4
60	16	16	10	3.5	9	6
70	23	20	16	4.8	14	8
80	33	25	-	-	23	10
85	-	-	30	8.1	-	-
90	46	31	-	-	-	-
100	60	36	60	13.1	63	16

Notes: 1-Based on stopping sight distance. 2-Based on headlight illumination criteria. 3-Based on comfort criteria.

Phasing of Horizontal and Vertical Alignments

Certain combinations of horizontal and vertical curves can result in drivers seeing an apparent distortion in the alignment or grade or both, even though the horizontal and vertical curves comply with design rules. Other combinations can hide a change in horizontal alignment for the driver. Thus, proper sequencing of horizontal and vertical curvature is important for accident prevention. However, such sequencing is usually attained at the cost of extra earthworks and a careful balance must be struck between the costs and benefits of such an undertaking. Examples of good and poor alignment designs are shown in Figure 4.10.



Example of good alignment design - a smooth-flowing appearance results when vertical and horizontal curves coincide

Example of a poor alignment design - uncoordinated horizontal and vertical curves

Figure 4.10 - Examples of good and poor combinations of horizontal and vertical alignments[11]

4.5 Roadside Safety, Education and Enforcement

4.5.1 Roadside Safety

The roadside environment and its design play an important role in road safety. Elements of this environment include:

- roadside furniture and obstacles
- road signs, markings and studs
- parking facilities, lay-bys and passing lanes
- traffic calming measures and lighting

Roadside Furniture and Obstacles
Whilst fulfilling important safety roles, both roadside furniture and obstacles can have negative safety implications as well which include:

- obstructing the view of road users and line of sight of drivers and pedestrians
- causing a risk of vehicles colliding into them

The ideal situation is to provide for a clear zone, which is kept free of hazards, including roadside furniture and obstacles. However, in cases where the provision of clear zones is too expensive or impractical due to topographical, environmental or other constraints, options should be considered to reduce the seriousness of the consequences. Figure 4.11 provides guidance on dealing with roadside hazards in order to provide a "forgiving roadside".

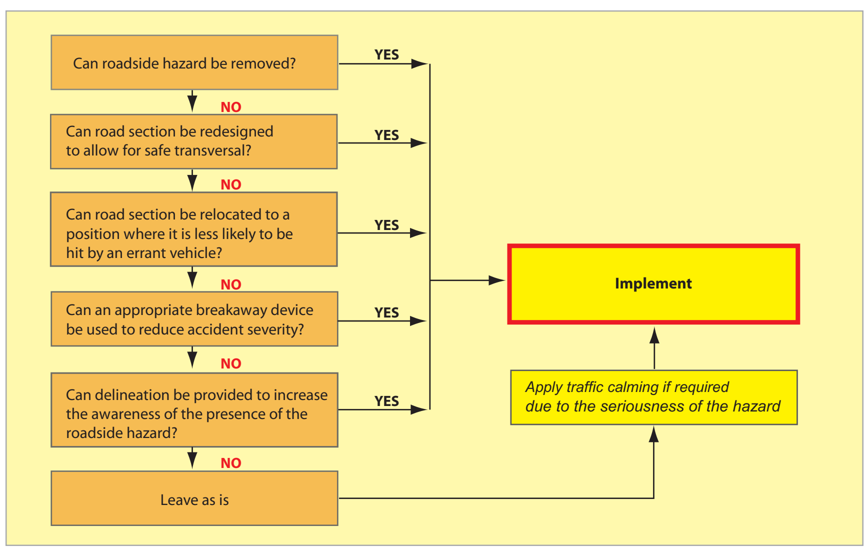


Figure 4.11 - Selection process to ensure a forgiving roadside

Roadside furniture *includes:*

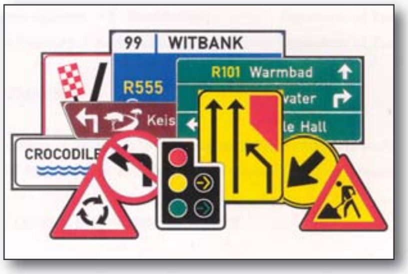
- *Road signs.*
- *Street lighting.*
- *Guardrails, etc.*

Roadside obstacles *include:*

- *Trees.*
- *Shrubs.*
- *Illegally positioned advertising signs within road reserve.*
- *Power lines or other utility poles within road reserve.*
- *Building structures.*
- *Deep side drains.*

An unforgiving roadside is one which is not free of obstacles that may cause serious injuries to occupants of light vehicles.

Non-standard cattle warning sign.



Various SADC traffic signs as contained in the SATCC Traffic Signs Manual.

Additional signage should be provided on dangerous curves.

Road Signs, Markings and Studs
Road safety is greatly facilitated by the provision of road signs, markings and reflective studs, which provide drivers with information about routes, road geometry, etc.

Road signs help to regulate traffic by assigning right of way and indicating regulations in force, warning road users of hazards and guiding the road user through navigational information. Road markings play a complementary role to road signs by conveying additional information to the driver, particularly in terms of delineating various road elements, such as the width of the lane or edge of the carriageway. Road studs, sometimes colour-coded, may be used to supplement road markings where these are subject to conditions of poor or limited visibility. The SATCC Road Traffic Signs Manual[18] should be used as far as possible to maintain consistency throughout the region.

Road signs generally need to be located within close proximity of the roadway (i.e. within the clear zone) and therefore need to afford some protection to errant vehicles. This can be achieved through the use of a simple breakaway device, using a notched wooden support.

Signs, particularly regulatory and warning signs, must be maintained in a sound order (i.e. reflectivity, cleanliness, visibility) as they play a crucial role in terms of road safety in giving information on rules and hazards further ahead (e.g. sharp curves, steep down grades, areas of high pedestrian activity, etc).

Regular maintenance (trimming) of grass verges and shrubs is particularly important at bends, around road signs, and where pedestrians and animals cross regularly. Poles for services and trees in the road reserve are hazardous for vehicles accidentally leaving the road, and they may also hinder sight distance. Large trees may need to be removed from the immediate roadside. The use of high standard guard-rails is safety efficient, but is very costly. Simpler types of guard-rails or delineators made of painted wooden poles may be used instead of the normal types of guard-rails.

In case of financial constraints, first priority in the placement and maintenance of signage should be given to regulatory and warning signs. Reflectivity of road signs must be adequate for the purpose, with higher reflectivity for warning signs and little (or no) reflectivity for guidance signs. Ideally, signs should be reflectorised, but ordinary paint is better than no sign at all. Road studs should only be considered on road sections where mist is prevalent. They can usually be discontinued on shoulders and be replaced by edge lines as they suffer significant wear and tear.

Channelisation of Traffic
Warning signs and reduced speed limits are particularly important near localised areas of high activity, such as stretches of road with ribbon development, where there is inadequate sight distance for normal overtaking manoeuvres, and the crests of hills. Speed calming devices can also be used as self-enforcing measures where compliance to warning signs and speed limits are low.

Simple, innovative measures may help to separate traffic and improve the road safety situation for non-motorized traffic in built-up areas.

Dedicated crossings provide increased safety for pedestrians if correctly positioned and marked.

By deterring drivers from using road shoulders, the use of shoulder humps can improve the safety of pedestrians and cyclists

The easiest and cheapest way of segregating pedestrian and vehicular traffic is through the use of road markings (i.e. demarcation of shoulders.) These can be in white paint; although the use of another colour (e.g. yellow) helps to identify the particular function of the marking. However, kerbs and even guard-rails can be used to physically separate pedestrians and vehicles. They can also be used to give added protection to pedestrians over bridge and other structures. If there is sufficient room in areas of high pedestrian movement, a footpath (perhaps raised with a kerb to dissuade vehicles from using it) can be provided, either alongside the road itself; or preferably separated by a grass or earth verge of some kind.

Even on low-volume roads there will be areas where pedestrian movements and traffic flow are sufficiently high that pedestrians should be provided with assistance to allow them to cross the road safely. This is especially important near schools and shops. This might involve providing clearly signed zebra crossings with or without a central refuge. As well as offering pedestrians protection, crossings and refuges promote traffic calming and also encourage pedestrians to cross where it is safer to do so.

Parking Facilities, Lay-bys and Passing Lanes

If the road topography permits, provision should be made for stopping and parking vehicles. Thus the road design should take account of the need for bus stops, the location of (official or unofficial) street vendors and market stalls, shops and schools. Off-road parking areas should also be provided for rickshaws and taxis and so on.

When there are steep gradients, provision can be made for faster vehicles to pass slow moving lorries and buses safely. This can be provided by having an additional 'crawler' lane, or occasional lay-byes for slow moving vehicles to pull in to let traffic queues pass. However, for LVSRs, the cost-benefit aspects of such measures need to be carefully considered.

At the end of steep descents, 'emergency' provision should also be made for out-of-control vehicles with brake-failures or those travelling too quickly. For example, beds of gravel can be provided to stop vehicles that are out of control and hazardous objects should be protected or removed.

Traffic Calming Measures

Although traffic-calming measures are generally aimed at reducing speeds and diverting traffic (decreasing traffic volumes) in urban areas there are a number of measures that are appropriate for LVSRs. They are normally used on sections of road where there are a high proportion of unprotected/ vulnerable road users (pedestrians, cyclists and animal drawn carts, etc), or where there is a localised (unexpected) change in the design speed. Speed calming measures can basically be categorized according to the extent to which they may have an effect, namely:

- localised traffic calming measures, which include warning signs and markings, speed humps, rumble strips, jiggle-bars, pinch-points, roundabouts together with road surface texture and colour
- continuous traffic calming measures, such as speed humps, along a stretch of road

Well-designed speed humps are an effective means of slowing down traffic.

Stray cattle are a traffic safety menace in some countries.

Road safety education for school children, an important awareness raising tool.

Speed humps are one of the most effective localised traffic calming measures, but require precision in design and construction to achieve a comfortable ride when traversed at the desired speeds but uncomfortable to drivers exceeding this speed.

Rumble strips in combination with traffic signs and/or speed humps, as appropriate, are traffic calming devices used to gradually reduce high speed before a dangerous spot. Community acceptance is very important for successful implementation of traffic calming devices.

Physical roadway design to enforce speed limits, such as narrowed lane width, can also be employed. This, however, has to be balanced by the need for passing opportunities, which is generally determined by the traffic mix. Visual narrowing of the roadway can have the same effect on speed as physical narrowing and can be achieved by using edge lines or omitting centre lines.

Animals

Many rural communities graze farm animals such as cows and goats on road-side vegetation. Ideally such animals should be tethered or supervised. This can be encouraged by providing community education programmes.

Domestic pets and wild animals can also pose a hazard for road users. In some SADC countries, fencing is used and can be effective if well maintained but the high cost means that it is seldom used along LVSRs. Often when fences are erected, gates are left open and gaps appear due to theft and vandalism, which rapidly reduces their effectiveness.

Street Lighting

This can help visibility and safety but is expensive and generally unaffordable in the context of LVSR. There might, however, be situations where street lighting of the road can be considered, for instance, when passing built-up areas, schools, hospitals and busy intersections.

4.5.2 Education and Enforcement

Education

Road safety education (RSE) is an important tool to raise awareness of problems and behaviours related to traffic and road safety. It involves teaching children, and often adults, to be safer road users. It does so by developing:

- knowledge and understanding of road traffic
- behavioural skills necessary to survive in the presence of road traffic
- an understanding of their own responsibility for keeping themselves safe
- knowledge of the causes and consequences of road accidents
- a responsible attitude to their own safety and to the safety of others

RSE should be provided during formal schooling by trained teachers who are provided with suitable resource materials. However, it should also be recognised that not all children attend school and that many adults have never received any proper road safety education. This can be overcome by providing community road safety education programmes in addition to formal teaching in schools. Where literacy rates are low, special teaching methods can be used (e.g. drama, singing and dance) while road safety education can be incorporated into other curriculum topics (such as science and geography). RSE needs to be relevant, practical (participatory) and regular and aimed at the child's level of education and social development. In some situations the children themselves can be used to educate either their parents or other children.

Road safety awareness campaign in progress.

Road safety publicity campaigns can also raise the awareness of problems and behaviour in addition to improving knowledge, shaping attitudes and behaviours, as well as stimulating discussion and debate. These publicity campaigns can include local drama performances in which tribal languages are used in order to reach illiterate persons. Community workshops, radio, television and cinema can also be successfully used.

Box 4.6 - Examples of innovative road safety initiatives

In Swaziland community involvement has been used to solve road safety problems. A project was recently launched whereby children were employed to control stray animals on rural roads during critical times of the year (e.g. during the Easter holidays.) The community was also mobilised to erect roadside fences. The road authorities provided the materials for construction. Once erected, the community became involved in the maintenance of the fences on an on-going basis which provided a valuable source of employment for them.

Enforcement is an essential component for improving road safety.

Enforcement

Traffic law enforcement is meant to achieve the safe and efficient movement of all road users including non-motorised traffic and pedestrians. In this regard, enforcement of traffic rules (such as speed limits, stop signs and rules at pedestrian crossing facilities) can be used to significantly improve road user behaviour and safety.

Unfortunately, because of a severe shortage of trained traffic police, traffic law enforcement is inadequate. As a result, drivers tend to disregard regulations and a general disregard for traffic law often gradually becomes the norm. This situation highlights the need to promote traffic law enforcement more vigorously, including the use of well mounted campaigns which, ideally, should be accompanied by education and publicity. The objective should be to improve the behaviour (and safety) of the majority of road users, rather than to simply 'catch' (and punish) a few. Moreover, such strategies should not be used as a simple means of raising money - but to improve safety.

4.6 Summary

The key points raised in this chapter are:

1. The functionality and characteristics of the LVSR network in the SADC region are quite different from those in industrialised countries. Traffic operations tend to be complex, comprising a mixture of both motorised and non-motorised traffic and there is often a relatively high proportion of commercial vehicles.

2. There are no geometric design standards for LVSRs in any SADC country based on in-country research into economic and safety factors. National standards are generally based on adaptations of those developed in industrialised countries and often do not cater for the characteristics of the road environment in the region.

3. No single design guide or manual can be recommended for use as they are based on different philosophies and make different assumptions or use different criteria for developing design values for the various geometric design elements.

4. It is essential for the designer to have a thorough understanding of the underlying criteria and assumptions that have influenced the development of existing design guides or manuals as a basis for adapting them, where necessary, to suit the local road environment.

5. Road safety is a major problem with accident rates being some of the highest in the world. There is an overriding need to incorporate road safety measures in the geometric design process. Road safety audits should be introduced as part of the road design process in all countries.

6. Road safety education and enforcement are key factors which can have a major influence on road safety and should be given high priority in order to promote a road safety “culture” for all ages of road users.

This chapter has reviewed established and more recent approaches to geometric design, particularly in the context of road safety. The need for adopting appropriate standards has been stressed and the scope for improving the appalling road safety situation highlighted. Design standards will have an impact on pavement design and road surfacing - subjects that are covered in Chapter 5.

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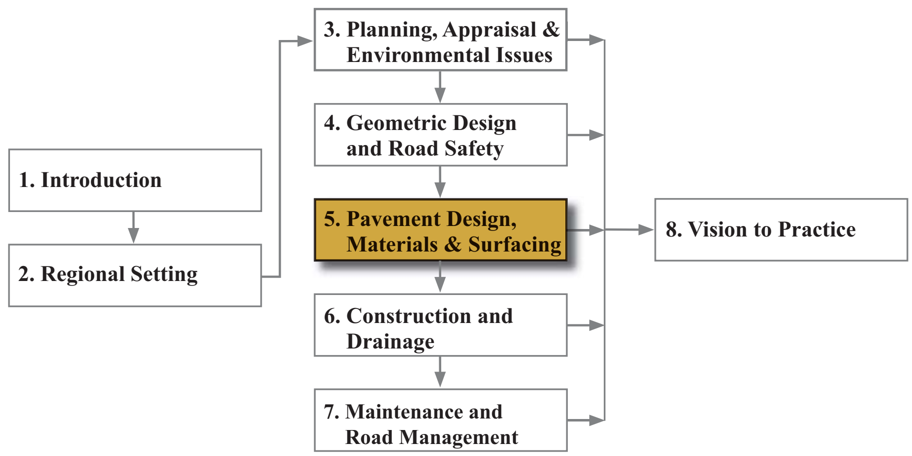
Chapter 5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Pavement Design, Materials & Surfacing

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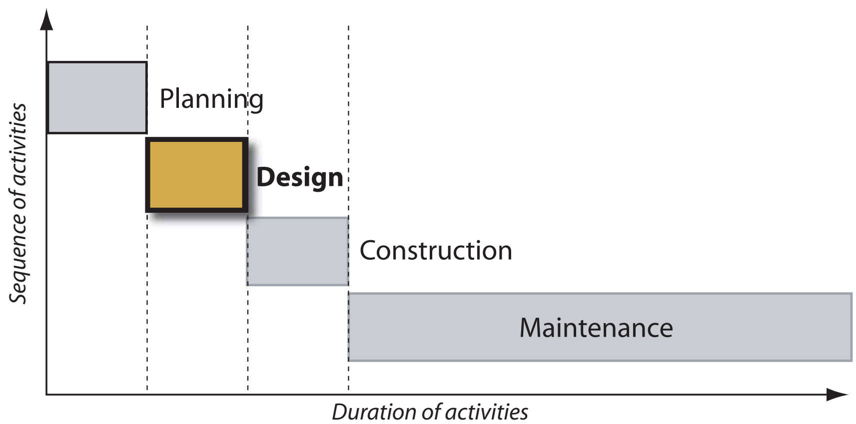
5.1 Introduction

5.1.1 Pavement Design



The objective of pavement design is to provide an economic structure, in terms of material types and thicknesses, that can withstand the expected traffic loading over a specified time, without deteriorating below a predetermined level of service. This provides a particular challenge for designers, as existing methods of pavement design, even those developed in the SADC region, generally cater for relatively high volumes of traffic (> 0.5 million Equivalent Standard Axles (ESAs)). As a result, such methods are often inappropriate for application to LVSRs for which environmentally induced, rather than traffic-induced, stresses tend to play a dominant role in pavement deterioration. Thus, there is a need to be very discerning in the application of current pavement design methodologies and to adapt them, where necessary, to suit the prevailing conditions of climate, materials, traffic loading and other related factors.

The outcome of the design process, in terms of the type of structure chosen, is influenced by the preceding phases of planning and geometric design and, in turn, determines many aspects of construction requirements. It also influences the level and type of maintenance necessary to keep the pavement at the design serviceability level. In order to ensure a successful outcome, there is a need to ensure that the design process is undertaken in a holistic manner that takes full account of a variety of influential factors, as discussed in Chapter 3.

Calcrete and laterite are typical examples of natural gravels which, although occurring throughout southern Africa, had generally been considered to be unsuitable for use in base courses. However, experience and full-scale trials in a number of SADC countries have demonstrated that these materials can be used successfully in the upper layers of pavements.

5.1.2 Materials

Naturally occurring soils and gravels are an important source of material for use in the construction of a LVSR. This is because these materials are relatively cheap to exploit by comparison with processed materials such as crushed rock. Moreover, in many SADC countries, they are often the only source of material within a reasonable haul distance of the road. Thus, because of the substantial influence that naturally occurring materials exert on the cost of a LVSR, typically about 70 per cent, it is essential that the benefits of using them are fully exploited in road construction.

Naturally occurring calcrete found under a relatively thin layer of overburden.

Unfortunately, many of the naturally occurring road building materials in the SADC region are disparagingly described as being “non-standard”, “marginal”, “low-cost”, or even “sub-standard”! This is because such materials are often unable to meet the required specifications, which are usually based on European or North American practice that did not always make provision for local conditions. However, there are many examples of naturally occurring materials, such as laterite and calcrete, that have performed satisfactorily despite being “sub-standard” with respect to their grading, plasticity or strength. Where failures have occurred, investigations have generally shown that poor quality construction or drainage problems were more likely the cause, rather than the materials themselves.

The use of local materials requires not only a sound knowledge of their properties and behaviour but also of the traffic loading, physical environment, and their interactions. In addition, it will require the use of appropriate pavement design methods and the application of appropriate design standards and materials specifications, coupled with construction quality that complies with the required standards and specifications.

The term “natural gravel” refers to a gravelly material occurring in nature as such, (e.g. laterite) or which can be produced without crushing. Some processing, to remove or break down oversize may still be necessary. However, a distinction is made between these “natural” gravels, and material produced from crushed hard rock, and is referred to as “crushed stone base”.

Box 5.1 - The challenge of using natural gravels

- Because of their mode of formation, involving intensive processes of weathering, many road-building materials in the SADC region tend to be highly variable and moisture sensitive. This requires the use of appropriate construction techniques and provision of adequate internal and external drainage.
- Standard methods of test that, for the most part, have evolved as a result of experience of soils in temperate zones, do not always give a true assessment of the performance of locally available materials when used in road construction.
- Conventional specifications apply to “ideal” materials and often preclude the use of many naturally occurring materials (laterites, calcretes, etc.) despite their good performance in service.

5.1.3 Surfacing

In situations of rapidly dwindling sources of gravel for maintaining unsurfaced roads, the bituminous sealing of a gravel road offers numerous technical, economic and environmental advantages and, in many cases, is unavoidable. However, because of the relatively low levels of traffic carried, there is need to provide a durable surfacing at the lowest possible life-cycle cost. Unfortunately, current specifications for traditional bituminous surfacings are demanding and exclude the use of local materials that could be suitable.

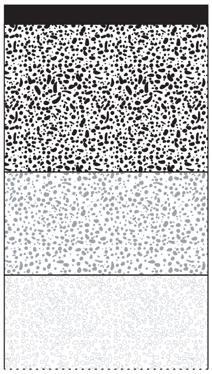
Providing a surfacing for a gravel road calls for the innovative use of local materials, which may often be of a non-standard nature, in situations where the use of conventional materials would be prohibitively expensive. Fortunately, in addition to the traditional chip seal or surface treatment, there are a number of alternatives which, although not yet widely used, can provide eminently cost-effective solutions.

5.1.4 Purpose and Scope of Chapter

The main purpose of this chapter is to provide a generic guide to the design of low-volume sealed road pavements using locally occurring materials to the greatest extent possible. This is based on research work and developments that have taken place in the SADC region with respect to the emergence of more appropriate design methods, specifications and test methods. The principal aim of this approach is to maximize implementation of previous research, which now exists in a disparate fashion and has not been adequately synthesized and packaged in an easily retrievable format for dissemination and implementation.

5.2 Pavements, Materials and Surfacing Terminology

Typical pavement structure.



5.2.1 Components

A road pavement typically consists of the following three primary components:

- surfacing
- pavement structure (base and subbase)
- subgrade

A typical LVSR pavement structure consists of a thin bituminous surfacing underlain by one or more layers of natural gravel.

Surfacing
The surfacing is the uppermost layer of the pavement and forms an interface with traffic and the environment. It normally consists of some kind of non-structural, impermeable bituminous surface treatment or a structural layer of premixed bituminous material (asphaltic concrete).

Base
The base is the main load-bearing and load-spreading layer of the pavement and normally consists of natural gravel, gravelly soils, decomposed rock, sands and sand-clays. The weaker materials are often stabilized with cement, lime or bitumen. On relatively highly trafficked roads, asphalt concrete and crushed stone may also be used.

Subbase
The subbase is the secondary load-spreading layer underlying the base and normally consists of a material of lower quality than that used in the base. This layer protects the subgrade and, importantly, acts as a construction platform and also provides a stiff platform against which the base can be adequately compacted.

Subgrade
The subgrade is the upper layer of the natural soil that supports the pavement structure. It may be undisturbed local material or soil imported from elsewhere and placed as fill. In either case, it is compacted during construction to give added strength. The ultimate strength characteristics of the subgrade dictate the type of pavement structure required, in terms of layer thickness and material quality, to reduce the surface load by traffic or the environment to a magnitude that can be supported without unacceptable permanent deformation.

Carriageway
The carriageway is that section of the roadway which is normally reserved for use by vehicular traffic. In many SADC countries such traffic may be both motorised and non-motorised.

The design of a LVSR may require a different approach to each of the pavement parameters compared with conventional design.

The shoulders provide a number of functions including lateral support for the pavement structure and accommodation for stopped vehicles. The shoulders may be sealed or unsealed, the implications of which are discussed in Section 5.4.3.

Each of the components of the pavement structure forms part of a typical road cross-section as shown in Figure 5.1.

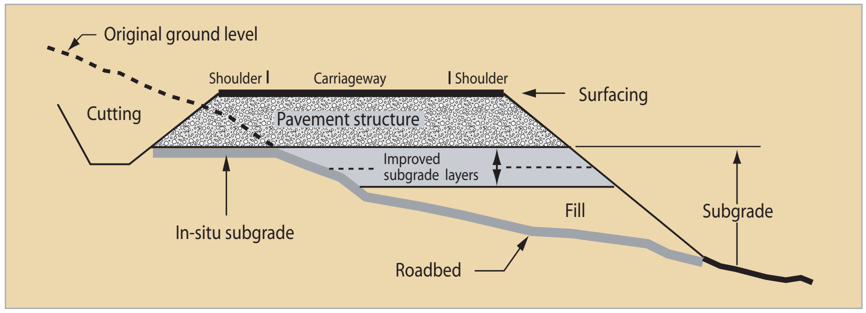


Figure 5.1 - Cross-section of a typical road pavement

5.2.2 Requirements of a Pavement

A pavement must be designed to meet both functional and structural requirements. Functionally, it should serve traffic safely, comfortably and efficiently at minimum or "reasonable" cost. Structurally, it is a load-bearing structure that is required to perform under the prevailing traffic and environmental conditions with minimum maintenance.

The pavement structure transfers the wheel loads from the surface to the underlying subgrade. As shown in Figure 5.2, the wheel load or pressure at the surface is effectively reduced within the pavement structure by being spread over a wide area of subgrade. The strength characteristics of the roadbed soil dictate the type of pavement structure required to spread the applied load and to reduce it to a magnitude that can be supported by the subgrade.

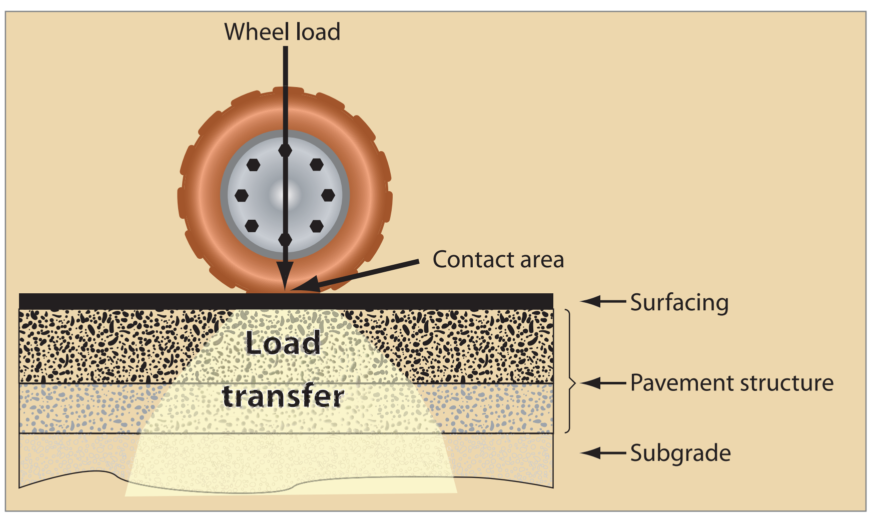


Figure 5.2 - Spread of wheel load through pavement structure

5.2.3 Performance

Pavements deteriorate gradually with time for a number of reasons, the two most important being:

- environmental effects
- traffic loading, comprising effects caused by wheel loads and tyre pressures, and which is dependent on the stresses and the number of times they are applied

On low-volume roads, benefits accruing from savings in vehicle operating costs will be small. As a result, in contrast to high-volume roads, lower levels of riding quality (roughness) can be tolerated over the life of the pavement.

These factors have the effect of reducing the riding quality of the pavement, as manifested by obvious visible features such as surface roughness, rutting and cracking in the manner illustrated in Figure 5.3.

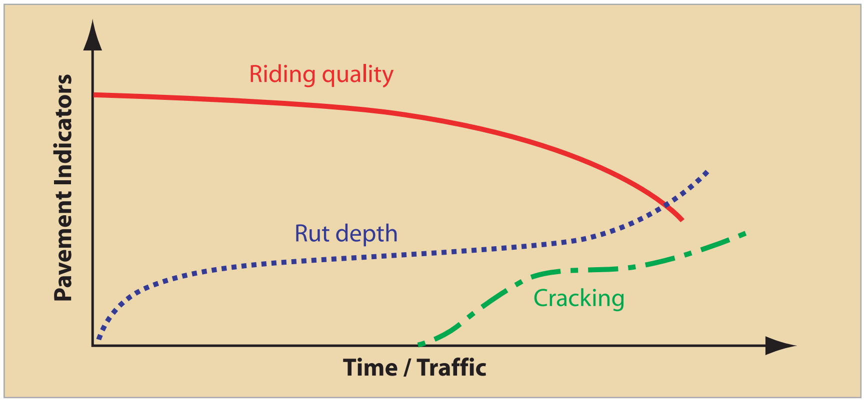


Figure 5.3 - Generalised pavement behaviour characteristics and indicators

Ultimately, the challenge of good pavement design is to provide a pavement that fulfils its function at minimum life-cycle cost at an optimal level of service. However, positive action in the form of timely and appropriate maintenance will be necessary to ensure that the assumptions of the design phase hold true over the design life.

Cracking of surfacing mainly due to oxidation and consequent hardening of bituminous binder.

Environmental Effects

Environmentally induced distress through climatic influences, including temperature and rainfall, play a particularly important role in the performance of low-volume road pavements. For example, high temperature can accelerate hardening of binders in road surfacings through loss of volatiles and oxidation, resulting in their loss of flexibility and consequent ravelling of the aggregate and brittle fracture of the layer.

High rainfall can also result in a change in the moisture content of the pavement and subgrade materials which, under poor drainage conditions and moisture sensitive materials, can adversely affect the pavement structure and its performance under traffic (Section 5.3.2).

Carbonation of materials stabilised with lime and cement can also occur. This is a reaction between the stabilising agents and carbon dioxide in the air or under road pavements and leads to a weakened material (Section 5.3.3).

Damage can occur to road surfacings as result of salt crystallisation. This effect is especially prevalent in dry climates and/or in circumstances where pavements have been constructed with materials or water with a relatively high salt content (e.g. minewaste) (Section 5.3.3).

Hydrogenesis is the upward migration of water vapour in the road pavement which, under certain climatic conditions, condenses under the road surfacing. The adverse effects of hydrogenesis on road pavements have not yet been fully quantified (Section 5.4.4.)

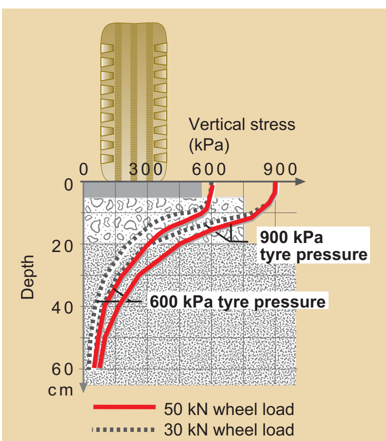
An example of rutting due to permanent deformation of the base layer caused by densification of material.

Traffic Loading

Traffic loading is responsible for the development of ruts and cracking that initiates within the pavement structure. Every vehicle using the road causes a small temporary deflection and a small permanent deformation in the pavement structure. The passage of many vehicles has a cumulative effect that gradually leads to significant permanent deformation and/or fatigue cracking. Overloaded vehicles, which are prevalent in the SADC region, cause a disproportionate amount of damage to the pavement structure, accelerating such deterioration.

On low-volume roads, the lack of traffic can also lead to ravelling and surface cracking. This arises because the kneading action of traffic keeps bitumen "alive" i.e. flexible.

It is noteworthy that most of the available manuals on pavement design tend to focus on load-associated factors whereas environmentally induced distress is often the major mechanism of distress for LVRs. The significance of these factors is discussed in Section 5.4.3.



Stress distribution versus depth in a pavement subjected to wheel loading [2].

Tyre Pressures

Tyre inflation pressure is an important parameter that can influence the performance of LVSRs. Prevailing tyre inflation pressures have risen steadily over the years and are now considerably higher (of the order of 900 - 1000 kPa) than those used on key road performance experiments, such as the AASHO[1] Road Test (550 kPa), on which many empirical pavement design methods have been based.

The effect of repeated high tyre contact pressures is to generate high shear strains in the upper layers of pavements. This is not normally a problem where pavements have been well designed and constructed. However, in certain situations, e.g. on steep grades or in poorly drained areas where moisture-sensitive, low-strength materials are used, it can be problematic and can result in the cracking of surface layers are rutting from plastic deformation of one or more of the pavement layers, causing shoving (shear failure) and breakdown of weak aggregates. In such situations, appropriate design and construction counter measures should be observed.

5.2.4 Perceived Causes of Deterioration of LVSRs

Based on workshops carried out in a number of SADC countries, the perceived deterioration effects of LVSRs were recorded. These are summarized in Table 5.1.

Table 5.1 - Deterioration effects on LVSRs

Parameter	Related Issues
Poor drainage	• water ingress to pavement structure • inadequate maintenance of drainage structures • poor roadside drainage/flood water scour • poor geometric design
Inadequate maintenance	• poor/lack of/insufficient maintenance • poor maintenance techniques • integrity of seal/delayed reseal/unsealed cracks

Overloading	• unexpected heavy loads after design • very high tyre contact pressures, sometimes associated with weakening of upper base layers due to crushing or carbonation
Quality of construction	• inadequate/poor compaction • poor workmanship/supervision/construction standards • inadequate use of appropriate plant • poor mixing of materials/permeable pavements
Materials quality	• inadequate classification of soils • non-availability of good natural gravels, presence of poor subgrade soils • salt damage • low quality of surfacings • sodic, dispersive and other problem soils
Environmental extremes	• climatic (temperature and weather) extremes • erosion of shoulders and side slopes
Design	• inadequate pavement design/design specifications • poor shoulder design/lack of sealed shoulders • flat terrain/low embankments/inadequate camber • increased generated traffic

The above perceived causes of deterioration of LVSRs are indicative of the range of important issues that should be addressed when considering the pavement, materials and surfacing aspects of such roads (dealt with in this chapter) are considered, as well as other aspects pertaining to construction and maintenance (dealt with in Chapters 6 and 7 respectively).

5.2.5 Terminology

As-dug, nodular laterite gravel used in LVSR construction.

Crushed limestone is a typical "standard" material that is produced by crushing of blasted, massive rock to a specified grading.

Materials

Naturally occurring materials: These include natural soils, gravel-soil mixtures and gravels. Little or no processing is required other than, possibly, loosening the in situ material by ripping and breaking down (usually with a grid roller) or removing oversize particles. The cost of such materials is, typically, about 25% of crushed stone. They may be used in their natural state or modified with small amounts of lime, bitumen or cement. Crushing may occasionally be required.

Standard/traditional materials: These are defined as materials which meet traditional specifications, such as those of the American Association of State Highway and Transportation Officials (AASHTO). Such materials are tolerant of construction mishandling and adverse environmental conditions and will probably perform well in most cases. However, when used as specified, their use is often excessively conservative for the level of performance required from LVSRs.

An essential feature of most traditional specifications for standard materials is a requirement for strict compliance with limitations on particle size distribution (grading), plasticity index and aggregate strength. This is partly to avoid the use of any materials in pavement layers that are susceptible to the weakening effects of water and frost. Crushed rock and river-washed and fluvio-glacial gravels are thus the predominant materials used for building roads in temperate climates. The export of these practices to tropical and subtropical regions has meant that the potential of natural gravels, especially in the drier areas of such regions, have often been neglected.

Laterite is a typical example of a "non-standard" material that has been successfully used in LVSR construction despite its non-compliance with traditional strength, grading and plasticity requirements.

A typical surface treatment operation - spraying a thin layer of bitumen onto a road surface prior to the application of aggregate.

Non-standard/non-traditional materials: These comprise any material that is not wholly in compliance with the specifications used in a country or region for a standard or traditional material, for example, as regards grading or PI. Nonetheless, it has become increasingly recognized worldwide that, under favourable circumstances, many such materials can and, indeed, have been used successfully. However, this requires an in-depth knowledge and experience of the properties of such materials and the conditions necessary for successful performance - requirements which have been facilitated by the extensive research work undertaken in the SADC region in the past 20 - 30 years.

It should be noted that the concept of "non-standard" in relation to materials is specific to a particular time and place associated with our level of understanding of the behaviour of the material and knowledge of how to use it. For example, forty or fifty years ago, gravel was considered as a nonstandard material because crushed stone, the "standard" material, was used in the construction of Macadam and Telford pavements.

Surfacing

A number of different terms are used to describe a road surfacing which, as described in Section 5.2.1, normally consists either of some kind of non-structural bituminous surface treatment or of a structural layer of pre-mixed bituminous material. Typical terms include:

- surface treatment
- surface dressing
- chip and spray
- chip seal
- sprayed seal

The above terms all essentially describe a similar product in that, in the construction of these seals, a thin layer of bitumen is sprayed onto the existing road surface (base or existing seal) and one or more layers of aggregate or sand are applied.

- asphaltic concrete

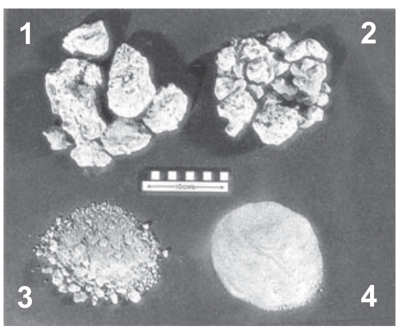
A layer of premixed materials (aggregate and bitumen).

5.3 Materials

5.3.1 Formation and Classification

In contrast to the abundant deposits of clean, durable, fluvioglacial gravels such as those used in much of Europe and the USA, the materials available for pavement construction from southern Africa have undergone considerable depths of weathering or pedogenesis[3]. The materials are therefore mostly residual weathered igneous rocks (e.g. basalt, dolerite and granite), metamorphic rocks (e.g. gneiss and quartzite), sedimentary rocks (e.g. shale and mudrocks) and pedogenic materials (e.g. laterite, calcrete and ferricrete). These pavement materials are generally weaker than those of northern Europe and North America but road subgrades, other than those in localized problem areas, e.g. "black cotton" soils or collapsible sands, tend to be generally stronger.

A simplified view of the formation of soils and rocks that form the backbone of road construction materials in the region is given in Figure 5.4. The manner in which such materials differ from conventional road building materials is presented in Table 5.2.



Four types of calcrete found in some SADC countries: (1) Boulder, (2) Nodular, (3) Powder, (4) Calcified Sand.

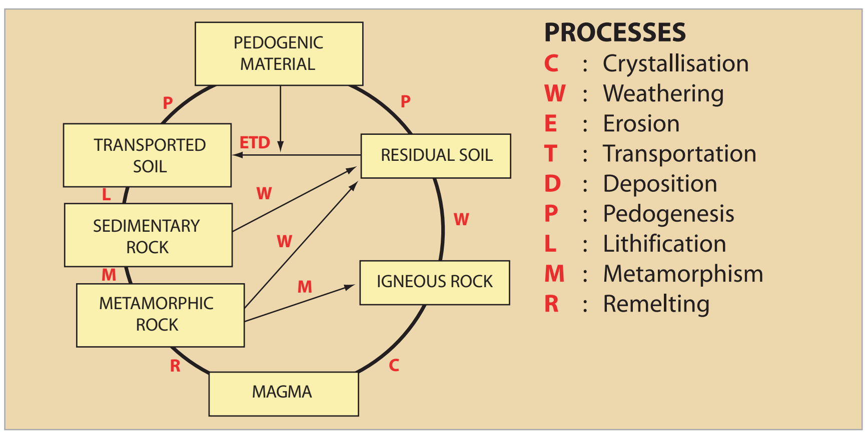


Figure 5.4 - Soil-Rock cycle[4]

Table 5.2 - Differences between conventional and pedogenic materials[3]

Property	Conventional (crushed rock base, river gravels, glacial outwash)	Pedogenic (laterites, calcretes, ferricretes, silcretes)
Climate	Temperate to cold	Arid, tropical, warm temperate
Composition	Natural or crushed	Varies from rock to clay
Aggregate	Solid, strong rock	Sometimes porous, weakly cemented fines
Clay minerals	Mostly illite or montmorillonite	Wide variety, e.g. halloysite, attapulgite
Cement/bonding agent	None (usually)	Iron oxides, aluminium hydroxide, calcium carbonate, etc
Chemical reactivity	Inert	Reactive
Grading	Stable	Sensitivity to drying and working
Solubility	Insoluble	May be soluble
Weathering	Weathering or stable	Forming or weathering
Consistency limits	Stable	Sensitive to drying and mixing
Salinity	Non-saline	May be saline
Self-stabilisation	Non-self-stabilising	May be self-stabilising
Variability	Homogeneous	Extremely variable

The road-making materials commonly used in the construction of LVSRs in southern Africa can mostly be classified as crushed or natural, residual or transported gravels and soils derived from the following main groups[5]:

Soils and granular materials in the SADC region are inherently variable in terms of their engineering properties such as plasticity, grading and strength. When considering their appropriate selection for LVSRs, it is important to consider how the compacted material will interact with the "road environment", i.e. moisture susceptibility, swell and collapse characteristics, particle degradation, durability, etc. Specialist testing may be required with basic rocks, pedocretes (calcrete, silcrete, etc) and various weathered materials.

- basic crystalline (e.g. dolerite, andesite, basalt)
- acid crystalline (e.g. granite, gneiss)
- high silica rocks (e.g. quartzite, hornfels, chert)
- arenaceous rocks (e.g. sandstone, conglomerate)
- argillaceous (e.g. mudstone, shale, slate, schist)
- carbonate rocks (e.g. limestone, dolomite)
- diamicites (e.g. tillite)
- pedocretes (e.g. calcrete, laterite, ferricrete, silcrete)

Each group has a characteristic range of properties and potential problems that should be taken into account in test methods and specifications. For example, a PI of up to 15 may be allowable in an unstabilised calcrete or laterite gravel base, whereas a value of more than 1 or 2 may be problematic in a base composed of a basic crystalline rock, even if stabilised[6].

Ultimately, the challenge of selecting pavement materials for low-volume roads in southern Africa is essentially one of quantifying the risk associated with departing from the use of traditional, high quality materials. For such materials, specifications rely heavily on experience with traditional "ideal" materials from more temperate climates which, as stated previously in this chapter, do not necessarily apply to local materials. Fortunately, the extensive research carried out in the region over the past two decades has gone a long way towards quantifying the conditions under which local materials can be used with confidence.

Weinert's N-Value

The Weinert N-value is calculated from climatic data as follows:

$$N = \frac{12.E_j}{Pa}$$

Where E_j = *evaporation during hottest month (January)*

Pa = *annual precipitation*

Influence of Climate

The southern African climate exerts a significant influence on the properties of natural road building materials, as well as on the subsequent performance of roads in which such materials are used. In this regard, the various climatic zones in the SADC region may be characterized by the Weinert N-Value which correlates broadly with mean annual rainfall, as shown in Table 5.3 [7].

Table 5.3 - Climatic zones: Approximate mean annual rainfall and N-values

Climatic Zone	Arid	Semi-arid	Sub-humid	Humid
Weinert N-Value	> 10	5 - 10	2 - 5	< 2
Mean Annual Rainfall (mm)	< 250	250 - 500	500 - 800	> 800

The climatic N-values for southern Africa are also significant in that they provide some indication of the dominant mode of rock weathering and the related engineering properties of the resulting products. The values N = 2, N = 5 and N = 10 are of particular significance and their contours are shown in Figure 5.5.

Figure 5.5 - Climatic N-value map of southern Africa[7]
(currently does not cover the entire SADC region)

The Weinert N-values and climatic zones provide an important insight into the properties and engineering characteristics of the naturally occurring materials of the SADC region. This fosters a clear understanding of the likely behaviour of these materials in particular environments and allows practitioners to design and build LVSRs in a wide range of circumstances with greater confidence.

In areas where N-values are greater than 5, mechanical disintegration - the physical breakdown of rock - tends to predominate. In areas where N-values are less than 5, chemical decomposition - the chemical alteration of a rock - predominates. This can lead to the transformation of certain minerals into some type of clay. From these divisions, very broad but important generalisations can be made about the soil profile, as indicated in Table 5.4.

Table 5.4 - Characteristics of materials in relation to climate (N-value)[7]

N-value	Material Characteristics	Significance of material properties
N < 2	Rocks are extensively weathered, often to depths of several metres, and decomposition is pronounced. Smectite minerals are the principal products of the decomposition of basic crystalline rocks.	Materials tend to have relatively high plasticity and are moisture sensitive. Basic igneous rocks are often not durable and prone to degradation in service. Careful attention should be paid to the internal and external drainage of pavement.
N = 2-5	Conditions similar to above but the thickness of residual soil cover gradually decreases as the N = 5 contour is approached.	
N = 5-10	Thickness of residual soil cover gradually decreases even further than above. Disintegration is the dominant mode of weathering.	
N > 10	All rock types weather by mechanical disintegration alone and the shallow residual soils are commonly granular and gravelly.	Materials have relatively low plasticity and are not particularly sensitive to moisture.

5.3.2 Characteristics of Pavement Materials

Materials used in pavement layers can be classified into four categories as follows:

- Unbound granular - 1. Unprocessed (naturally occurring, as dug).
  - 2. Processed (screened, mechanically stabilized).
  - 3. Highly processed (crushed to specified grading).
- Bound granular - 4. Cement, lime, bitumen or pozollanic material.

The material types described above derive their strength from a combination of the following intrinsic properties[8]:

- inter-particle friction
- cohesive effects from fine particles
- soil suction forces
- physico-chemical (stabilization) forces

The relative dependence of a material and the influence of moisture on each of the above components of shear strength will significantly influence the manner in which they can be incorporated within a pavement. For example, unbound/unprocessed materials (e.g. calcrete or ferricrete) are highly dependent on suction and cohesion forces for development of shear resistance that will only be generated at relatively low moisture contents. Special measures therefore have to be taken to ensure that moisture ingress into the pavement is prevented. Otherwise suction forces and shear strength will be reduced as illustrated (notionally) in Figure 5.6, possibly resulting in failures.

Box 5.2 - Soil suction and its contribution to shear strength - basic concepts

Soil suction: As the grain size of a fine-grained material decreases, the total exposed surface area becomes very large in relation to the volume of voids within it. Under these circumstances, molecular forces, which are only effective for very short distances from the surface, begin to play an increasingly important role. They are essentially attractive in nature and can provide significant additional strength. The forces are equivalent to, and can be described by, a reduction in pressure in the "pores"or voids in the material. This is referred to as *suction*.

As the magnitude of soil suction can be very much greater than normal atmospheric pressure, the effective pressure can become highly negative. Its value depends not only on the amount of fluid in the pores (voids) but also on its nature, i.e. dissolved salts. As the pores fill with water, the magnitude of the suction decreases rapidly.

Soil strength and stiffness: The shear strength of granular materials and normally consolidated fine-grained soils is described by the well known effective stress equation:

Shear strength = (cohesion) + [(normal stress) – (pore pressure)] Tan (angle of internal friction)

The strength and stiffness of a pavement layer are reduced if pore pressure is increased (at high moisture contents) and, conversely, are increased when pore water pressure is decreased (at low moisture contents). When the pore pressure equals the total stress, internal friction becomes negligible and the shear strength is equal to the cohesion.

Thus, it is pore water pressure or suction of the water in the pavement, rather than the amount of water, that affects pavement behaviour. Two soils of different textures may have similar strength, and stiffnesses, even though their moisture contents may be quite different.

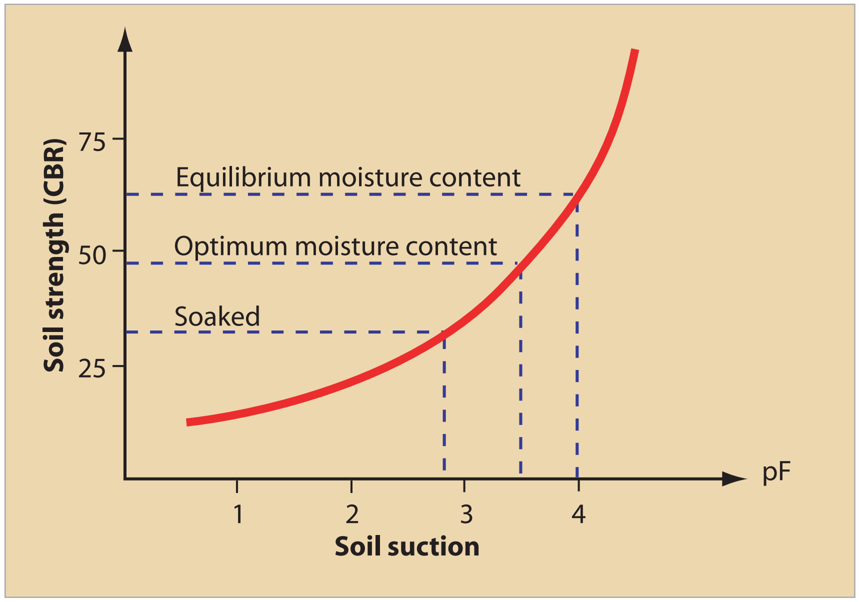


Figure 5.6 - Illustrative soil strength/suction relationship

Problem Soils and Materials

By virtue of their unfavourable properties, a number of soils and materials fall into the "Problem soils and materials " category and, when encountered, would normally require special treatment before acceptance in the pavement foundation. This category of soils and materials includes:

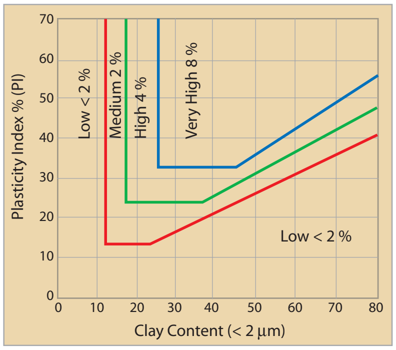
- low-strength soils
- expansive clays ("black cotton" soil)
- collapsible sands
- dispersive soils
- organic soils
- saline soils or presence of saline water
- weathered materials

The characteristics, investigation, testing and design counter-measures to deal with problem soils are well covered in the literature and are not dealt with in depth in this Guideline. In dealing with such materials, a careful balance has to be struck between the cost of the counter-measures and the benefits to be derived, bearing in mind the relatively small user benefits generated by LVSRs.

The main characteristics of typical problem soils found in the SADC region are highlighted below:

Low-strength soils: Soils with a soaked CBR of less than 3 per cent (< 2 per cent in dry climates) are described as Low-strength soils. Typical treatment measures for such soils include:

- removal and replacement with suitable material
- chemical or mechanical stabilization (see section 5.3.3)
- elevation of the vertical alignment to increase soil cover and thereby redefine the design depth within the pavement structure



Qualitative measure of soil expansiveness (Modified van der Merwe Chart).

N.B - PI test to be carried out on material passing the 0.075 mm sieve.

Typical longitudinal cracking caused by large volumetric changes in an expansive soil subgrade.

Collapse settlement in excess of 150 mm after impact rolling.

Expansive soils: These clay soils exhibit particularly large volumetric changes (swell and shrinkage) following variations in their moisture contents. They shrink and crack when they dry out and swell when they get wet. The cracks allow water to penetrate deep into the soil, hence causing considerable expansion. This results in deformation and unevenness of the road surface, since the expansion and the subsequent heave are never uniform. Furthermore, if the side slopes are not gentle enough these volume changes may produce lateral displacements ("creep") of the expansive soil. When dry, some expansive soils present a sand-like texture and are prone to erosion to a much greater extent than what would be normally expected from their plasticity and clay content.

The measures chosen to minimize or eliminate the effects of expansive soils for LVSRs need to be economically realistic and proportionate to the risk of potential pavement damage and increased maintenance and user costs. Typical methods include:

- realignment, where possible
- excavation and replacement
- chemical treatment
- minimising moisture changes
  - wide (at least 2 m), sealed shoulders
  - avoidance of side drains
  - gentle side slopes (1:6 or flatter)
  - minimum earthworks cover of 0.6 m

Expansive "black cotton" soil exhibiting widely spaced shrinkage cracks.

Collapsible sands: These sandy soils occur mostly in the arid and semi-arid regions of southern Africa, particularly in the Kalahari Desert regions of western Botswana and eastern Namibia. They exhibit a weakly cemented soil fabric which, under certain circumstances, may be induced to rapid settlement. A characteristic of these soils is that they are all unsaturated, generally have a low dry density and a low clay content. At the in-situ moisture content they can withstand relatively large imposed stresses well in excess of the overburden pressure with little or no settlement. However, without any change in the applied stress, but an increase in moisture content, additional settlement will occur, as shown in Figure 5.7. The rate of settlement will depend on the permeability of the soil. Useful indicators for assessing the collapse potential of a soil include density and grading (ref. Table 5.5). More rigorous tests to quantify collapse potential include the single odometer test in which an undisturbed sample is loaded at its natural moisture content up to 200 kPa and then saturated. The collapse potential of the material is a mathematical expression, in percentage terms, of the reduction in

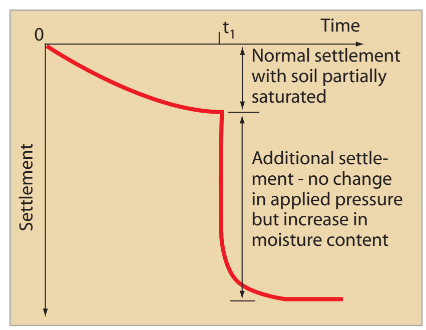


Figure 5.7 - The basic concept of additional settlement due to collapse of soil fabric[9]

Box 5.3 - Conditions to be satisfied before collapse settlement can occur

- the soil must have a collapsible fabric
- it must be partially saturated
- the applied load must exceed the overburden pressure
- there must be an increase in moisture content after the load has been applied

voids ratio, in relation to the thickness of the potentially collapsible material and provides a guide to the potential severity of the problem.

Table 5.5 - Indicators of collapse potential and severity of problem[10]

Property	Guide to Collapse Potential[a]
Dry density (kg/m^3)	< 1600
% passing 2.0 mm and retained on 0.75 mm sieve	> 60%
% passing 0.075 mm sieve	< 20%
Relative density	< 85%

Collapse Potential (%)	Degree of Severity
0 - 1	No problem
2 - 5	Moderate trouble
6 - 10	Trouble
11- 20	Severe trouble
> 20	Very severe trouble

a – See Botswana Road Design Manual

Methods of dealing with collapsible soils includes the following:

- Excavation of material to a specified depth below ground level and replacement in thin lifts (typically 200 mm).
- Ripping of the road bed, inundation with water and compaction with heavy vibrating rollers.
- Use of high energy impact compaction at in situ moisture content.

The above measures are all relatively expensive to undertake and a careful balance should be struck between the costs and benefits of their application to LVSRs

Dispersive soils: These soils, some of which are clayey gravels, are easily eroded in the presence of water - a property that makes them problematic when they occur in cut slopes and in drainage channels. They are generally found in areas where the climatic N-value is between 2 and 10. They have almost no resistance to erosion, are susceptible to pipe developments in earthworks, crack easily and have low shear strength. Their identification involves the use of a combination of indicator tests, observations of erosion patterns, soil colour, terrain features and vegetation.

The following measures are typically employed where dispersive soils are encountered:

- erosion protection in cut slopes and drainage channels
- modification with 2% to 3 % lime

Salt damage may appear in the form of "blistering", "doming", "heaving" and "fluffing" of the prime or surfacing.

An example of severe distress to a runway surfacing due to salt attack resulting in damage within two years of its construction.

Saline soils or presence of saline water: The presence of soluble salts in pavement materials or subgrades can cause damage to the bituminous surfacings of LVSRs. This problem occurs mostly in the semi-arid regions of southern Africa where the dry climate, combined with presence of saline materials (often calcrete or minewaste) and/or saline ground or surface water, create conditions that are conducive to the occurrence of salt damage. Such damage occurs when the dissolved salts migrate to the road surface, mainly due to evaporation, become supersaturated and then crystallize with associated volume change. This creates pressures which can lift and physically degrade the bituminous surfacing and break the adhesion with the underlying pavement layer. Generally, the thinner the surfacing layer is, the more likely the damage, primes being the most susceptible and thick, impermeable seals the least susceptible.

It is quite feasible, and often cost-effective, to use saline materials in LVSR construction, rather than haul non-saline material great distances. However, this requires a sound knowledge of the project environment and the type of salts and salinity levels in the materials as a basis for designing and specifying appropriate preventative measures and monitoring of salt levels during and after construction.

Guidelines for the prevention and repair of salt damage to roads and runways have been developed based on research work carried out in the region and elsewhere[11,12]. These guidelines provide guidance on methods of testing and measurement of salts as well as on repair methods where damage has already occurred.

Sample of weathered, decomposed basalt, showing altered clay minerals in rock vesicles and cavities.

Weathered materials: Weathered materials, such as basic igneous rocks (e.g. basalt, dolerite), occur extensively in southern Africa and are commonly used in the construction of LVSRs, either in their natural (untreated) or chemically stabilised states. The properties of these materials are governed by their mineralogy and apparently sound rock containing secondary minerals liable to decomposition by weather or traffic must be avoided. Specialised testing may therefore be required to assess their long term durability for which reference should be made to Draft TRH13: Cementitious stabilisers in road construction[13].

Waste Materials

Numerous types of "waste" materials can be recycled into aggregates and additives for use in LVSRs. However, an imaginative approach is required to recognise their potential use - a use that would alleviate the need to open new gravel sources, thereby reducing the environmental impact of the provision of new, or upgrading/rehabilitation of existing infrastructure. The use of waste materials, where feasible, will also reduce the impacts associated with their stockpiling (e.g. dust from a dump).

Examples of waste materials that can be considered for use in LVSRs include:

- waste rock dumps at mines and quarries (base and surfacing aggregate)
- slags from metal processing (base course)
- crushed glass (surfacing aggregate)
- clinker ash (subbase and base course)
- fly-ash (mechanical stabilization agent on fines-deficient material)
- phosphogypsum (mechanical stabilization agent, subbase material)
- tyres (ground for bitumen rubber, chips for light-weight fill, complete for bank stabilization and slope-failure repairs)

Prior to use, materials should be subjected to a standard testing programme, as well as an environmental assessment to ensure that no significant environmental impacts occur as a result of the use of the material. As certain materials may also have relatively high soluble salt contents, additional tests should be carried out to ensure that their presence will not influence the performance of the surfacing.

5.3.3 Soil Improvement

Where suitable naturally occurring gravels are not available within an economical haulage distance, it may be necessary to resort to some form of stabilisation – the process by which additives are used to enhance the properties of subgrade and pavement materials - in order to improve the materials' properties, including strength, volume stability, durability and permeability.

The additives in common use in the region are:

- granular materials } Mechanical stabilisation
- portland cement
- lime (quicklime and hydrated lime)
- pozzolans (fly-ash, pumice, scoria)
- bitumen and tar

(portland cement; lime; pozzolans; bitumen and tar) } Chemical stabilisation

The following factors influence the selection of the most suitable method of treatment:

- site constraints
- materials
- climate and drainage
- economics of the various options

A general guide to the stabilisation of soils with cementitious stabilisers is given in Draft TRH13[13], while the suitability of the various types of stabilisation additives is given in Figure 5.8.

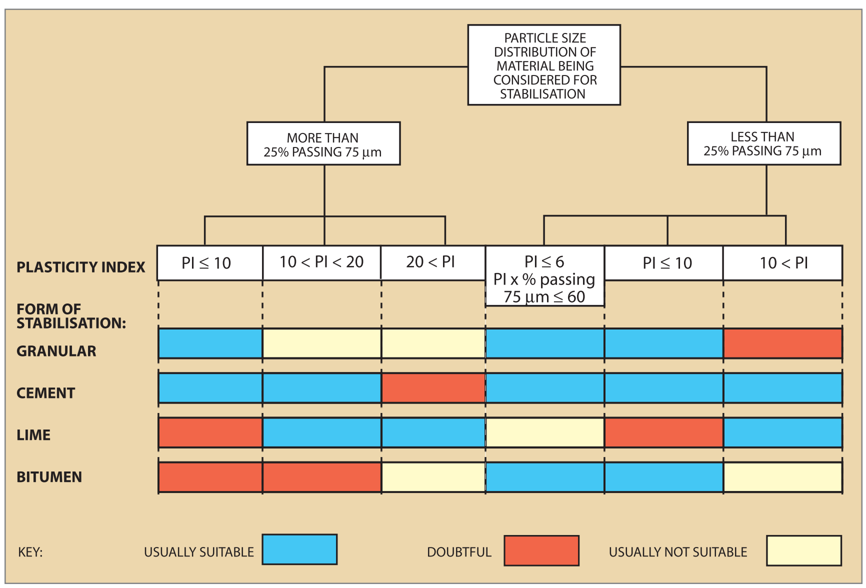


Figure 5.8 - Guide to the method of stabilization[14]

When mixed in the appropriate proportion, two non-standard materials, such as Kalahari sand and Calcrete, often satisfy the specifications of a standard/traditional material.

Mechanical Stabilisation

The simplest, and often cheapest, form of stabilisation, as well as the easiest to construct, can be achieved by blending two natural materials, usually gravel with sand, to form a mechanically stable layer. This usually results in the following advantages:

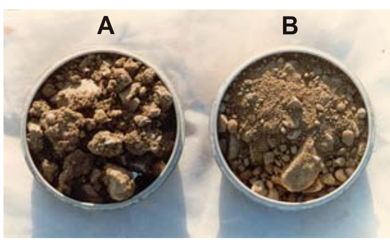
- improved CBR
- lowering of PI
- lowering of OMC
- improved workability

The results of a laboratory investigation of the mechanical blending of a natural gravel (calcrete) with sand is shown in Figure 5.9. As is evident from the figure, the CBR of two samples (A and B) increased significantly by over 40 per cent (20 per cent sand added) and 30 per cent (30 per cent sand added) respectively.

Figure 5.9 - Results of mechanical blending of calcrete with sand[15]

In blending granular materials with finer-grained materials, care must be taken to ensure that the plasticity of the fines fraction is not increased to such a degree that there is a loss in stability.

Improved workability of clayey materials



A: Untreated - relatively unworkable.
B: 3 % lime-treated - more workable.

Chemical Stabilisation

The main objective of chemical stabilisation is to enhance the suitability of locally available natural gravels for pavement construction, thereby avoiding the need to import other materials. This can often lead to more cost-effective use of available materials with the following beneficial properties by comparison with the untreated parent material:

- increased strength or stability
- improved load-spreading capability
- increased resistance to erosion
- reduced sensitivity to moisture changes
- improved workability of clayey materials

As indicated in Figure 5.8, the choice of chemical stabiliser will depend on the material to be stabilised and the position in the road pavement it is to occupy. These stabilisers are generally applied at relatively low dosages, typically between 3 and 6 per cent. However, if problems are to be avoided, they must be subjected to careful and well-controlled processing and construction.

Specifications for chemically treated materials vary in different parts of the world and for different road authorities. For southern African conditions, reference should be made to Draft TRH[13].

Potential problems or pitfalls with these types of materials include:

- propensity to crack because of traffic loading or environmental conditions, particularly with cement treatment
- degradation of the cementing action due to carbonation, particularly in the use of cement and lime treatments
- requirement for greater levels of skill and control during construction (compared with that required for untreated materials) to achieve a satisfactory product

Phenolphthalein reaction in stabilised sub-base.

Box 5.4 - Effects of carbonation

Lime- and, to a lesser degree, cement-stabilized soils, can lose strength through carbonation. This effect is particularly evident in lime-stabilised fine-grained, relatively weak soils (especially calcretes). When used as base course material, prolonged exposure of these stabilised soils to the air before sealing can also result in a weak upper layer being produced prior to surfacing. Subsequent crushing of the aggregate as well as poor bonding between the surface and the base can occur, leading to pavement failure. Measures that ameliorate the effects of carbonation during the stabilisation process include[16]:

- immediate covering with the next layer of material
- immediate application of a bitumen prime coat
- full moist curing (with no drying of the surface)
- construction of layer with a sacrificial thickness to be bladed off

Proprietary Chemicals: Various proprietary chemicals and road additives are sometimes used to improve the properties of natural gravels for use as pavement materials. However, their use is very project specific and they should be used with caution. There is relatively limited and well documented experience of their successful use and well-controlled trials are required to confirm their suitability for use with specific materials. The more common chemicals include:

- wetting agents to improve compaction
- natural polymers (e.g. ligno sulphonates)
- synthetic polymer emulsions (e.g. acrylates)
- modified waxes
- sulphonated oils
- biological enzymes

5.3.4 Specifications

Inexperience tends to cultivate a rigid adherence to specifications.

Specifications are meant to exclude most unsatisfactory materials for use in roads by placing limits on their various properties such as grading, plasticity and strength. The derivation of appropriate limits requires an intimate knowledge of the performance of local material in a specific environment (climate and drainage measures) and for specific traffic loadings. The challenge is basically to relate the materials' physical properties with performance in a particular environment.

Traditional specifications for base gravels typically specify a soaked CBR @ 98% modified AASHTO density of ≥ 80%, PI of ≤ 6 and adherence to a tight grading envelope. However, research in the region has shown that when due consideration is given to factors such as traffic, subgrade strength, drainage, pavement cross section, etc, substantial relaxations can be made on selection criteria with significant cost savings.

Until relatively recently, most of the specifications used in the SADC region tended to reflect temperate zone specifications emanating from Europe and North America. Typical conventional specifications rely heavily on experience and on "ideal" materials having the following properties:

- restrictive grading requirements
- low plasticity (PI < 6)
- high road base strength (soaked CBR > 80 per cent at 98 per cent modified AASHTO compaction)

The above limits originate from situations very different from those prevailing in much of the SADC region in terms of material types, climate, traffic characteristics, standards, etc. and, when applied, would rule out many natural gravels available for use in LVSR construction. Standard specifications cannot address all possible variations in environmental conditions or cover all types of material. Judicious interpretation of existing specifications and application of local knowledge can produce project-specific and more appropriate specifications.

The art of the roads engineer consists, to a great extent, in utilizing specifications that will make possible the use of materials he finds in the vicinity of the road works. Unfortunately, force of habit, inadequate specifications and lack of initiative have suppressed the use of local materials and innovative construction technologies.

Box 5.5 - Transferability of materials specifications

Materials specifications are not always simply transferable from one region to another. What may be appropriate in one region, in relation to such factors as material type, climate and traffic loading, may well be quite inappropriate in another region where these factors may be quite different. In the final analysis, every material has its uses and limitations and must simply be matched to the traffic, climatic and other conditions influencing its performance. ***Costly failures in some cases as well as over-conservative, uneconomic designs in others can result when conventional materials specifications are rigidly applied in the region.***

It is also important to bear in mind that specifications are tied directly to the test methods used in carrying out research work. For example, most of the research work carried out in the region on pedocretes is tied to ASTM-type methods. It would therefore be inappropriate and risky to apply BS standards to evaluate pedocretes unless suitable compensatory adjustments were made to the test results.

Volume 1 of a five-volume series of reports on the outcome of the 4-year programme of research on highway engineering materials.

The successful use of non-standard materials is largely dependent on the availability of a local specification developed for specific operating environments. The formulation of these "customized" material specifications has enabled the use of many materials that otherwise would be rejected if traditional specifications were used.

Based on a 4-year programme of research in highway engineering materials[17], specifications have been developed for a variety of commonly occurring natural gravels in which their geological origin as well as climatic and traffic loading factors relevant to the region are taken into consideration. The research focused on how existing sealed road pavements performed with time and traffic in different climatic conditions and found that:

- The minimum standard of 80 per cent soaked CBR for natural gravel bases was inappropriately high for many LVSRs. *New limits are recommended depending on traffic, materials and climate.*
- The grading envelopes for natural gravel bases were narrow. *Alternative (wider) envelopes are recommended for relatively lightly trafficked roads.*
- Traffic below 500,000 cumulative ESA was not a significant factor in pavement deterioration. Many road sections performed well even when subjected to a high degree of overloading and with PIs of up to 18. *New limits for PI have been recommended.*
- Drainage was a significant factor on performance, even in dry areas. *A minimum crown height of 0.75 m above the invert level of the side drain is recommended.*

As a result of the SADC regional research work, revised specifications have been derived for the major groups of natural gravel roadbase materials found in the region (quartzitic gravels, weathered rocks, lateritic gravels, calcareous gravels and sand) for a range of traffic levels up to 500,000 ESA and subgrade types not currently catered for in existing guides. Thus, they should be incorporated in country documents and considered for use in the design of LVSRs.

Proper planning is essential for a successful materials prospecting survey.

5.3.5 Prospecting

Large quantities of natural gravel are required for constructing and maintaining LVSRs. It is therefore essential that optimum use be made of all materials available at the lowest possible cost. Very often, gravels occur as relatively small localized deposits scattered around the landscape, and are usually overlain by a cover of soil and vegetation which makes them very difficult to find. Consequently, modern exploration techniques must be employed to ensure that available materials are located as efficiently as possible, instead of the "haphazard or random" methods often used.

The art of prospecting involves looking for clues as to the occurrence of useful materials and then digging to see what may be there. Learning to identify features that indicate the presence of gravel from interpretation of maps and other information is a key activity in prospecting. However, the most important parts are the desk study followed by the field survey and pit evaluation. Information about gravels in the landscape typically comes from five main sources, viz:

- geological information from geological maps and reports
- soils information from agricultural soils maps and reports
- botanical indicators
- landscape information from topographic maps, aerial photos and satellite images
- other local information

Experience has shown that a significant amount of material used is often located during construction when excavation equipment is more readily available than in the pre-construction, site investigation phase.

The above sources of information are all analysed together to assess the likelihood that gravel may occur at a particular place. A typical flow diagram for materials prospecting is shown in Figure 5.10.

Desk Study
- Specification and quantity of materials required
- Interpretation of background material
- Provisional materials map

↓

Plan Survey
- Decide on methodology and procedure
- Carry out in-house or use consultants
- Consider environmental aspects

↓

Find and Map Sources of Materials
- Reconnaissance field survey
- Detailed field survey

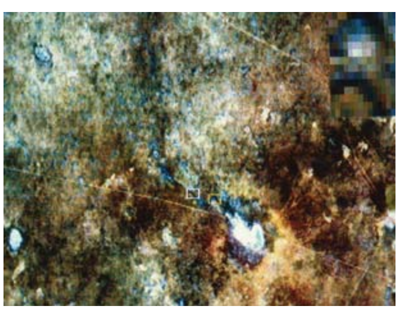
↓

Source Evaluation (Laboratory)	**Source Evaluation (Field)**
• Laboratory testing	• Areal extent • Profile description • Visual classification

↓

Data Capture and Feedback
- Reporting

Figure 5.10 - Flow diagram stages for material prospecting [26]



Aerial photographs and satellite images are valuable sources of information which can be used for materials location.

Liquid Limit device used in the determination of the plasticity index of a soil.

5.3.6 Testing

Standards

Materials testing is normally prescribed in standards put out by various countries, of which the BS (British), ASTM (American) and TMH (South African) are in common use in the region. Unfortunately these methods differ in many respects with regard to the actual test procedure and the method of testing. For example, authorities employing a BS Liquid Limit device will obtain a Plasticity Index (PI) that is, on average, 4 units higher than that obtained on an ASTM Liquid Limit device[18]. It is important, therefore, not to mix testing standards because the differences in test procedure alone are sufficient to explain the difference in material quality apparently tolerable by pavements in different SADC countries[6]. Ideally, materials testing standards in the SADC region should be standardized so as to facilitate intra-regional research efforts, technology transfer and reporting.

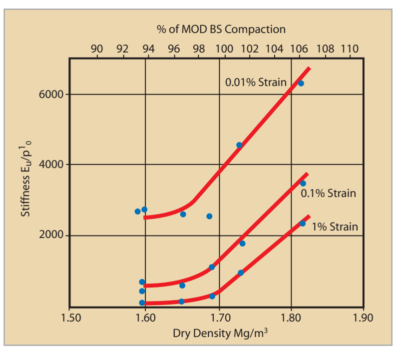
Tests

Materials testing is carried out to assess the various properties of road construction materials as an indicator of their likely performance in service. A wide variety of laboratory tests is available for this purpose and includes:

- classification
- moisture content
- density
- strength
- stiffness
- durability
- chemical
- special

In addition, there are various field tests which may be used to assess the properties of the placed material such as:

- in situ strength (in situ CBR test, Dynamic Cone Penetrometer or Clegg Hammer)
- stiffness (deflection testing, e.g. Falling Weight Deflectometer, Benkelman Beam, Plate Bearing)
- permeability (water permeability test)



Stiffness-dry density relationship, lateritic gravel (Kenya)[19].

The two critical properties which are known to exert a major control on the performance of natural gravels in road construction are *strength and stiffness*. Both are dependent on moisture content and density and can be affected by the wetting and drying history or to the compaction process to which the material has been subjected in reaching the density involved. Ideally, therefore, *for pavement design purposes, the strength and stiffness properties of natural gravels should be assessed from samples made up at the densities and critical moisture contents likely to occur in the road and not at pre-determined values.* A number of tests are used for assessing the suitability of natural gravels for use in road pavements. The more common ones are discussed below:

California Bearing Ratio (CBR) test: One of the most important strength tests in common use is the CBR test, an arbitrary test that was originally devised as a method of comparing subgrade soils with crushed rock. Because of its ease of use in comparison with the more complex methods of strength measurement, it is widely used in many empirical methods of pavement design. However, its use as a primary means of selecting natural gravels for LVSRs has long been questioned.

Strength assessment of pavement materials

There is a tendency to attach a strength rating to a material without realizing that this is of little value if divorced from an appreciation of the probable in-service moisture content and density condition. Irrespective of what strength criteria are advanced, they will be abused if no attempt is made to test for strength at moisture content and density conditions expected in the field.

*The **Resilient Modulus** of a soil is a measure of its resistance to displacement, i.e. its susceptibility to rutting under a wheel load.*

*The **Elastic Stiffness** of a soil reflects its load spreading characteristics. Thus, a high E value implies good load-spreading ability while a low E value implies that loads will be concentrated on the subgrade and high flexural strains will occur.*

Box 5.6 - How appropriate is the CBR test as a means of selecting natural gravels for use in LVSR pavements?

- The CBR test is an empirical test that was developed using empirical observations of satisfactory pavements over a number of subgrades with the objective of establishing subgrade bearing capacity, *not the adequacy of the pavement material*.
- The test has poor reproducibility, with an overall coefficient of variation of the order of 20 per cent. This characteristic makes the interpretation of test results, especially for inherently variable natural gravels, very imprecise. For example, for a true mean value of 80, the CBR can range from 48 to 112, a range that can lead to vastly differing interpretations of the suitability of the soil for use as a pavement material.
- The test does not measure any of the fundamental engineering properties of soil that critically influence its performance, such as elastic stiffness (E_r) and resistance to permanent deformation or resilient modulus (M_r). As indicated in Figure 5.11, materials with the same CBR could have very different elastic stiffnesses and, as a result, in similar service conditions could perform quite differently because of their different load-spreading ability.

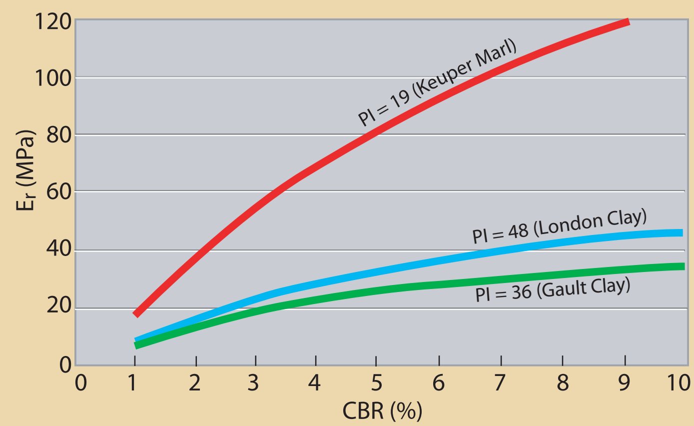


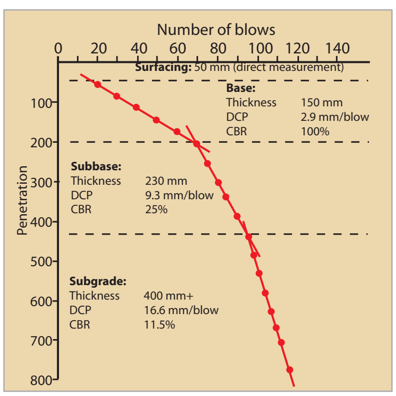
Figure 5.11 - Relationship between elastic stiffness and CBR for a stress pulse of 40 kPa[21]

In view of the above, it may be concluded that, if the CBR test is used to justify the use of a material which departs substantially from the traditional grading and plasticity limits (as is the case with most pedogenic materials), then, on its own, it may well not be appropriate.

Whilst it is not suggested that the CBR test be discarded, it is recommended that other tests, such as the Texas Triaxial and K-Mould tests, could be very useful supplementary tests for selecting natural gravels for use in LVSR pavements. These tests can provide information that is often more discriminating as regards material performance than the CBR test[22].

Texas Triaxial Test: An alternative to the CBR test, is the *Texas Triaxial test* which is used in Texas, Australia and Zimbabwe. This test is based essentially on the relative stiffness of the material in the form of stress strain characteristics and measures the fundamental strength parameters - cohesion and angle of internal friction. It is less empirical than the CBR test in that more of the coarse fractions of gravels can be subjected to test. Moreover, in the test the sample is tested as a whole, and the results are less prone to specific conditions under the CBR plunger.

The DCP test in progress.



Typical DCP test result plot.

Of particular importance is the ability of the Texas Triaxial test to assess the potential benefits gained by allowing the moisture content at compaction (optimum moisture content) to decrease to the predicted equilibrium value in the pavement. This makes the test particularly suitable for predicting the sensitivity of the strength of the material to changes of moisture, thereby allowing the material strength to be assessed at in-service moisture/density conditions.The test is somewhat more time consuming to carry out than the CBR test.

K-Mould Test: The K-Mould test is a laboratory soil strength test that was developed in the USA in the late 1970s[23] because of the need for a rapid, direct measure of soil strength under conditions that are reasonably representative of those anticipated in the field. The test is essentially a compression test in which a cylindrical soil specimen is constrained in an axially rigid but laterally flexing steel mould such that, as axial compression occurs, the lateral expansion of the soil is met by a constantly increasing lateral resistance, much as occurs in field loading conditions.

Research carried out at the CSIR shows that the K-Mould test is able to determine the elastic moduli of untreated road building materials with relative simplicity and a great degree of accuracy in a single loading cycle[24]. Thus, although not yet commonly used, the K-Mould test may provide a useful means of determining the elastic stiffness of natural gravels where required, in contrast to the more complex, time-consuming and costly repeated load triaxial tests that can hardly be justified for LVSRs.

Dynamic Cone Penetrometer (DCP): The DCP test is particularly worthy of mention because LVSRs are very often constructed on existing gravel roads with necessary improvements in vertical and horizontal alignment. The use of the DCP can provide a rapid, effective, low-cost, non-destructive method of estimating the strength of in situ materials. Methods have been developed in the region for strengthening existing gravel roads to provide LVSRs designed on the basis of the in situ DCP-CBR and design traffic level[25]. This information can then be used with existing catalogue pavement structures to provide the most economical pavement structure for a particular set of conditions.

5.3.7 Materials Inventory

As part of the materials prospecting process, considerable benefits can be realised through the development and use of materials inventories, particularly at the planning and design stages of LVSR projects. The common uses of such inventories are summarized in Table 5.6.

Table 5.6 - Common uses of materials inventories

Common Use	Related Factors
Record keeping	• Central record keeping. • Source of readily available/easily retrievable information. • Reference for future development.
Reducing costs	• Reduced consultancy costs.
Materials management	• Rapid/easier materials location and identification. • Input into national engineering geological maps.
Link to other management systems	• Development of pavement performance relationships for input into pavement management systems. • Interface with existing laboratory management systems. • Input into road failure investigations.

Specifications and research	• Support to on-going research. • Fine-tuning local materials and design specifications. • Development of local materials/performance correlations.
Other	• Potential source of revenue.

Despite the potential benefits of establishing materials inventories, their sustainability needs to be given careful consideration in terms of such factors as:

- institutional capacity
- regular system maintenance, updates and upgrades
- staff training

A first step in establishing a comprehensive inventory is to assemble, in a simple database, materials information from existing materials reports prepared by contractors and consultants.

The challenge of pavement design for low-volume roads

"I have always felt that in many respects it is easier to design a pavement for a high volume rather than a low-volume road for several reasons. On the low-volume road, for example, we are continually striving for low cost, which makes our design extremely sensitive from the standpoint of thickness, quality of pavement and surfacing materials, geometric design, and many other factors".

Eldon Yoder - one of the most prominent pavement designers of our time.

5.4 Pavement Design

5.4.1 Objective

The objective of pavement design is to produce an engineering structure in terms of thickness and composition that is in "harmony" with the local environment, will distribute traffic loads efficiently and provide a satisfactory level of service, whilst minimizing the whole-life cost of the pavement, i.e. both initial construction and subsequent maintenance costs. To achieve this goal, sufficient knowledge of the materials, traffic, local environment (particularly climate and drainage) and their interactions is required to be able to predict reasonably the performance of any pavement configuration. In addition, there should be a clear view as to the level of performance and pavement condition that is considered satisfactory in the circumstances for which the pavement structure is being designed.

Pavement design for low-volume roads presents a particular challenge to designers. This is largely because, until relatively recently, such roads were not specifically catered for and the step from a gravel road to a paved road was a large one. Moreover, pavement engineers are required to consider carefully the environment within which LVSRs have to be provided, in a manner which is often much more demanding than with HVRs.

5.4.2 Pavement Design System

The many variables and interactions that influence the final choice of road pavement make it appropriate to adopt a "systems" approach to pavement design in which all influential design factors are considered within an appropriate pavement design system. Figure 5.12 shows such a Pavement Design System. The various elements that comprise the system are discussed below, with particular emphasis on their relevance to LVSRs.

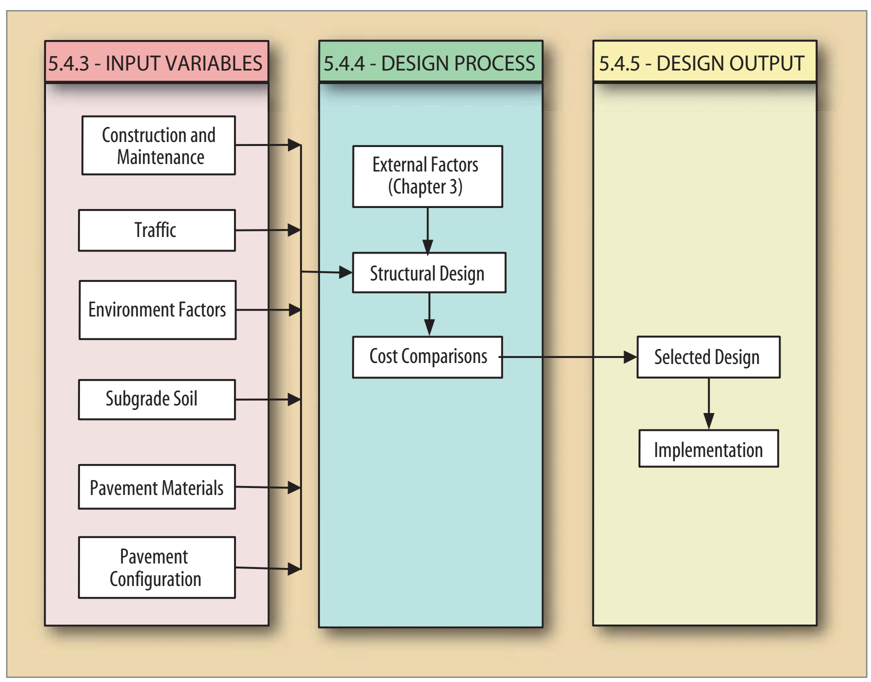


Figure 5.12 - Pavement design system

5.4.3 Input Variables

Construction and Maintenance Factors

Construction and maintenance policies can influence the type of pavement structure which is adopted. In addition, the properties of many materials are dependent on construction influences, including level of compaction and extent of sub-surface drainage provided. These latter factors are particularly important in the context of low-volume roads and are discussed later in this section. The more general construction and maintenance issues are discussed in chapters 6 and 7.

Traffic

The deterioration of paved roads caused by traffic results from both the *magnitude* of the individual wheel loads and the *number of times* these loads are applied. For pavement design purposes it is therefore necessary to consider not only the total number of vehicles that will use the road but also the axle loads of these over the design life of the road.

Design life - the period during which a pavement would be expected to carry the anticipated traffic at a satisfactory level of service without requiring major rehabilitation work.

Design life (Years): The design life of a pavement depends on a number of factors including, particularly, its function. Thus, a major trunk road fulfilling an obvious economic function and carrying high volumes of traffic, for which any major disruption would be very costly, would normally be designed for a longer design life than a tertiary/access road serving a primarily developmental or social function and carrying relatively low volumes of traffic. Table 5.7 provides some guidance on the selection of design life.

Table 5.7 - Pavement design life selection guidance

Design data reliability	Importance/level of service	
	Low	High
Low	10 yrs	10 - 15 yrs
High	10 - 15 yrs	15 - 20 yrs

Notwithstanding the attraction of employing staged construction strategies from a purely economic point of view, this approach is not recommended if there is any risk that maintenance and upgrading will not be carried out correctly at the appropriate time.

*The ADT is defined as the total annual traffic summed for **both** directions and divided by 365. However, for pavement design purposes, the traffic loading in **one** direction (in the heavier loaded lane) is required.*

Traffic estimation: This is determined on the basis of appropriate traffic surveys to establish the traffic volume by each traffic class in terms of the [Annual] Average Daily Traffic [A](ADT). The various types of traffic surveys available for determining *baseline* traffic flows have been dealt with in Chapter 3, Section 3.2.7.

Following the establishment of baseline traffic, further analysis is required to establish the total design traffic based on a forecast of traffic growth in terms of normal, diverted and generated traffic. Such forecasts are very sensitive to economic conditions in developing economies and the various factors to be considered are dealt with in detail in various texts on pavement design such as Overseas Road Note 31[27]. Moreover, for relatively shorter term design strategies (traffic <0.1 million ESA), an elaborate traffic analysis is seldom required, as environmental rather than traffic loading factors often determine the performance of the roads.

Construction traffic can be a significant proportion (sometimes 20 - 40 per cent) of total traffic on LVSRs as shown in Figure 5.13 and should be taken into account in the design of the pavement.

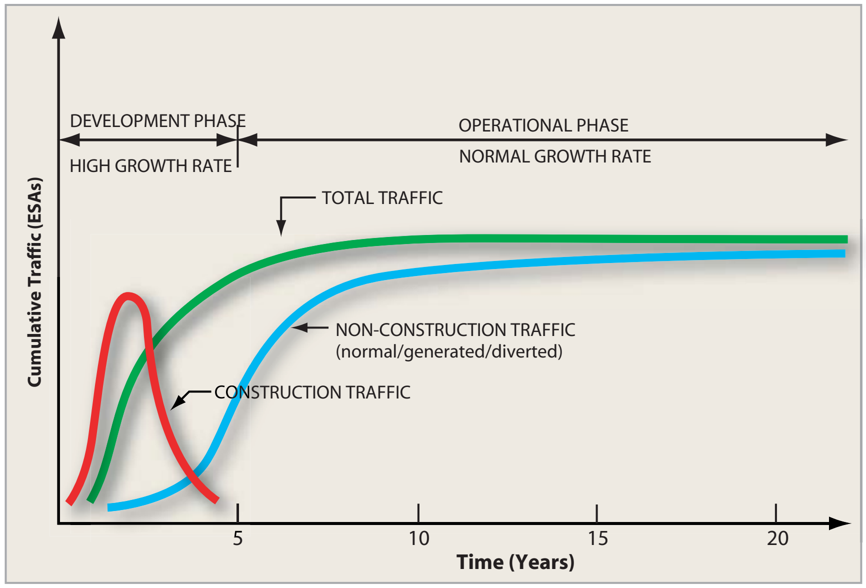


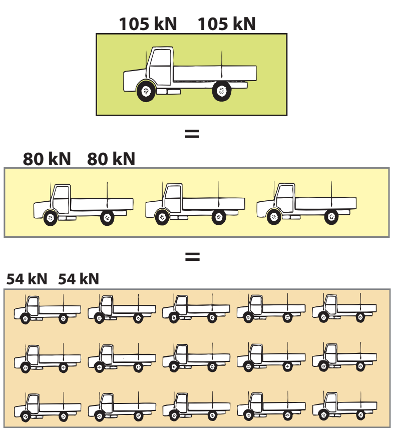
Figure 5.13 - Typical traffic growth pattern for a LVSR

Axle loading: The damage inflicted on road pavements depends very strongly on the axle loads of the vehicles and the number of times they are applied. Axle load data for design purposes can be obtained from surveys of commercial vehicles using the existing road or, in the case of new roads on new alignments, from existing roads carrying similar traffic. Methods of carrying out such surveys were described in Section 3.2.7 of Chapter 3.

The damaging power of a particular axle-load is generally expressed in terms of an equivalent "standard axle" - a concept that effectively reduces the varied nature of the traffic loadings to a single parameter in terms of structural damage to a pavement. The expression that is used for defining the equivalence factor of any axle load is based on the Fourth Power Law derived from the AASHO Road Test [1], as follows:

$N = (W/Ws)^n$ where
- N = load equivalence factor
- W = axle load
- Ws = standard axle
- n = power law exponent

For design purposes, the power law exponent, n, is generally assumed to lie in the range 4 - 4.5 (typically taken as 4.2). It is noteworthy, however, that the value of n is strongly influenced by pavement type (granular, cemented, etc) and mode of distress (rutting, fatigue, subgrade deformation, etc), strength of subgrade and stiffness and may vary from less than 1 to over 18! [28].



Three groups of heavy vehicles with equal damaging effect.

There is some evidence in the SADC region to indicate that the value of the exponent of 4.2 may not be appropriate for some LVSRs constructed with natural gravel road bases in which the main deterioration mode is often rutting. The significantly different axle loadings on the two lanes of a road in the region, where a range of "sub-standard" calcareous materials were used as road base, enabled an estimate to be made of the damage law exponent. This was found to be between 2 and 3, a value which has been confirmed by other investigations carried out in the region [29].

Cumulative equivalent standard axles: Following the traffic and axle load surveys described above, the cumulative equivalent standard axle loading over the design life of the road is determined by multiplying the number of axle loads in each load group of the entire load spectrum in the heaviest trafficked lane by the relevant equivalency factor.

Environmental Factors

Environmental factors - essentially in terms of moisture and temperature - have a profound effect on pavement performance. This is particularly the case with low-volume roads where environmentally induced distress rather than load-associated distress determines pavement performance[17]. As illustrated in Figure 5.14, it is only at relatively higher traffic levels that load-associated distress plays the dominant role in pavement performance.

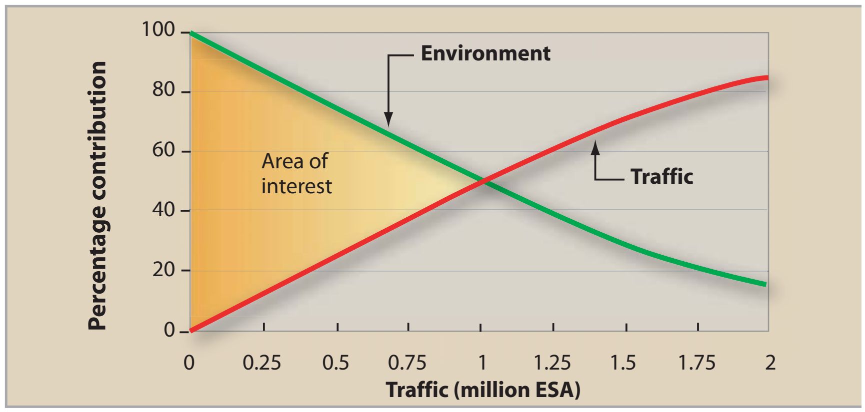


Figure 5.14 - Traffic loading versus dominant mechanism of distress

Investigations carried out in the region indicated quite clearly that traffic below about 300,000 to 500,000 ESA was not a significant factor in pavement deterioration.

Most design methods used in the SADC region cater for relatively high volumes of traffic, typically in excess of 0.5 million ESA over a 10 - 15 year design life, for which attention is focused on load-associated distress. However, for the large proportion of low-volume roads that exist in the region, carrying typically less than 0.3 million ESA over their design life, priority attention should really be paid to mitigating the effects of the environment, particularly rainfall and temperature, on their performance, as discussed below.

Climate: The moisture environment in which a pavement operates is a major influence on its performance because the strength and stiffness of the pavement materials and subgrade are critically dependent on moisture content. In turn, moisture content is influenced by the climatic zone in which the pavement is located.

Moisture environment: Arguably the most important challenge faced by the designer is to provide a pavement structure in which the detrimental effects of moisture are contained to acceptable limits in relation to the traffic loading, nature of the materials being used, construction/maintenance provisions and degree of acceptable risk. This challenge is accentuated by the fact that most low-volume roads will be constructed from natural, often unprocessed, materials which tend to be moisture sensitive. *This places extra emphasis on drainage and moisture control for achieving satisfactory pavement life* for which the following factors require careful assessment at the design stage:

- rainfall and evaporation pattern
- permeability of surfacing
- depth of water table relative to the pavement structure
- type of subgrade material
- relative permeability of pavement layers (permeability/no-permeability inversion)
- pavement configuration
- whether shoulders will be sealed or not

The various sources of moisture infiltration into a pavement are illustrated in Figure 5.15.

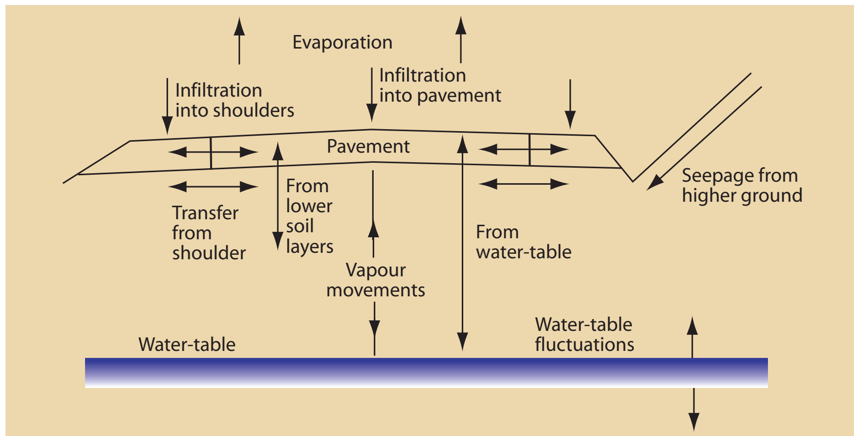


Figure 5.15 - Moisture movements in pavements and subgrades (NAASRA, 1987)[30]

Permeability: Moisture movements of any of the types illustrated in Figure 5.15 are controlled not only by the availability of moisture from the various sources but also by the *permeability* of the pavement, subgrade and surrounding materials. The permeability of the material will control the rate at which moisture moves through the material. The relative permeability of adjacent materials may also govern moisture conditions. A significant decrease in permeability with depth or across boundaries between materials (i.e. permeability inversion) can lead to saturation of the materials in the vicinity of the permeability inversion.

Box 5.7 - Significance of material permeability in pavement design

No permeability inversion: It is essential for good internal drainage that permeability inversion does not occur. This is achieved by ensuring that the permeability of the pavement and subgrade layers are at least equal or are increasing with depth. For example, the permeability of the base must be less than or equal to the permeability of the subbase in a three-layered system. To achieve this, it is necessary to measure or assess the permeability of the pavement and subgrade layers.

Permeability inversion: A permeability inversion exists when the permeability of the pavement and subgrade layers decreases with depth. Under infiltration of rainwater, there is potential for moisture accumulation at the interface of the layers. The creation of a perched water table could lead to shoulder saturation and rapid lateral wetting under the seal may occur. This may lead to base or subbase saturation in the outer wheeltrack and result in catastrophic failure of the base layer when trafficked. A permeability inversion often occurs at the interface between the subbase and subgrade since many subgrades consist of cohesive fine-grained materials. Under these circumstances, a more conservative design approach is required that specifically caters for these conditions.

Shoulder sealing is highly beneficial to the performance of LVSRs, especially where moisture sensitive materials are used.

Where permeability inversion is unavoidable, the road shoulder should be sealed to an appropriate width to ensure that the lateral wetting front does not extend under the outer wheeltrack of the pavement. Lateral drainage can be encouraged by constructing the pavement layers with an exaggerated crossfall wherever a permeability inversion occurs. Although this is not an efficient way to drain the pavement it is inexpensive and therefore worthwhile. Full under-pavement drainage is rarely likely to be economically justified for LVSRs.

In order to make due allowance in the design process for the effects of moisture changes on subgrade and pavement strengths, assessment of these strengths should be made at the highest moisture contents likely to occur in the materials during the design period.

In terms of pavement design, the two moisture zones in the pavement which are of critical significance are:

- the equilibrium zone
- the zone of seasonal moisture variation

Box 5.8 - Prediction of moisture content for use in pavement design

From extensive research work carried out in South Africa (in locations representative of much of southern Africa), it was found that[31]:

- In LVSR pavements over a deep water table (which covers much of the rural road network of the SADC region), moisture contents in the equilibrium zone normally reach an equilibrium value about two years after construction and remain reasonably constant thereafter.
- In the zone of seasonal variation, the pavement moisture does not reach an equilibrium and fluctuates with variation in rainfall. Generally, this zone is wetter than the equilibrium zone in the rainy season and it is drier in the dry season.
- The zone of seasonal variation of moisture extends horizontally from 600 mm to 1000 mm from the edge of surfaced pavements, and is more prominent in the upper layers.
- To reduce substantially the probability that the part of the pavement immediately under the wheel load is influenced by seasonal variations, it has been found that the minimum width of sealed shoulders should be one metre for design traffic of less than 3 million ESA and 1.2 metres for design traffic greater than 3 million ESA.

From the above, it follows that, if the pavement of a typical LVSR has un-surfaced shoulders, the outer wheeltrack will lie over the zone of seasonal variation, and the field material strength in this zone becomes critical in the design of LVSRs (see Figure 5.16). However, for LVSR pavements with sealed shoulders at least one metre in width, the traffic loads will lie over the equilibrium zone where the field material strength may be more confidently predicted, and the use of unsoaked material strengths in design become possible.

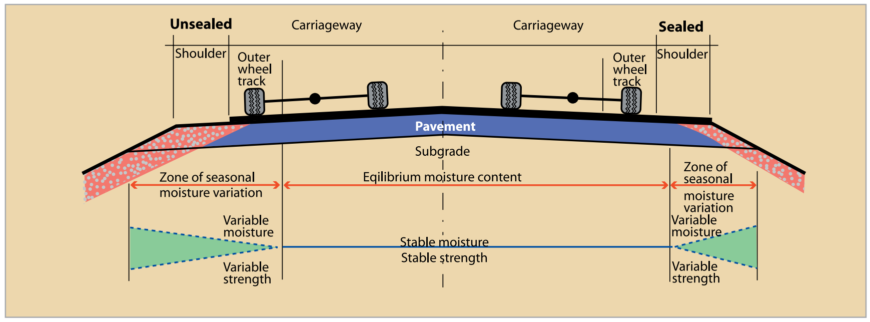


Figure 5.16 - Moisture zones in a typical LVSR

Temperature and humidity: Temperature and humidity play an important role in the performance of a road pavement with a bituminous surface, especially on low-volume roads. For example, ultraviolet radiation from sunlight causes a continuous slow hardening, reduction in elasticity and consequent embrittlement and cracking of the bitumen. Once the surface integrity has been lost, water can then penetrate the cracks into the underlying pavement structure, leading to a reduction in pavement strength and to an increased rate of deterioration under repeated wheel loads.

Various combinations of temperature and humidity can also give rise to *hydrogenesis* (i.e. the aerial-well effect) and the migration of water under a bituminous surfacing. An explanation given for this phenomenon is that ambient air, after penetrating the porous shoulders of the pavement, flows through the aggregate pavement layer[32]. Under certain temperaure conditions, water vapour in the air is then transferred to the surfaces of the aggregate particles where it forms a liquid water film. From this explanation, it is tentatively suggested that hydrogenesis could occur under the surfacing of bituminous pavements with a mean base course temperature above 20^{O}C and especially if the diurnal base course temperature range is greater than 10^{O}C. These conditions are usually found in the arid and semi-arid areas of the SADC region in summer. Thus, with moisture sensitive natural gravels, some allowance may have to be made for hydrogenesis in the design of the pavement.

The density to which a subgrade material is compacted can have a significant effect upon its strength. Variability in density is also a matter of concern as it will result in differential deformation due to traffic compaction.

Consideration should be given to the depth to which effective compaction can be achieved. In some circumstances, the strength of the unimproved subgrade below the depth of effective compaction may be a critical consideration in the design of the total pavement system.

Measures to overcome the adverse effects of temperature, including a judicious choice of surfacing type and binder, are discussed in Section 5.5.5.

Subgrade Soils

The support provided by the subgrade, in terms of its stiffness, is the most important factor determining pavement design thickness, composition and performance. The stiffer the subgrade, the less the layer thicknesses and component material strengths required to carry a given traffic loading. As emphasized in Chapter 6, every effort should be made to exploit the maximum stiffness potential of the subgrade by compacting to refusal with the heaviest plant available. However, care should also be taken to avoid overstressing of some soils, especially those with a bonded fabric which can break down under excess compaction.

For a given material type, the subgrade strength and stiffness are dependent on the conditions at construction and during service in terms of *moisture content* and *density.* It is therefore essential that estimates of these two parameters be obtained as a basis for establishing the *design subgrade condition,* which provides a basic input into most low-volume road design methods.

From investigations carried out across a wide range of climatic regimes and soil types in the SADC region [17,31], the field/optimum moisture ratios measured at the wettest time of the year are given in Table 5.8.

Table 5.8 - Variation of subgrade field/optimum moisture content with climatic zone[10]

Weinert N-Value	> 4 (arid/semi-arid)	2 - 4 (semi-arid/ sub-tropical)	< 2 (sub-tropical/ humid)
FMC/OMC*	0.5 - 0.7	0.75 - 1.25	1.0 - 1.5

* Measurement made in outer wheel track of pavement

The conclusions drawn from this research[17] provide critical inputs in the design of LVSRs and may be summarized as follows:

- the most important variables affecting equilibrium moisture content of the subgrade are material type and climate, with the effect of the former predominating
- subgrade moisture content increases with finer, plastic materials and generally varies inversely with maximum dry density, but directly with optimum moisture content and soaked moisture content
- the equilibrium moisture content in the subgrade increases with wetter climates; in the subbase and base it appears to be independent of climate
- the ratio of equilibrium to optimum moisture content in the subgrade, and to a lesser extent in the subbase, increases with wetter climates, but in the base it is almost independent of climate

These values highlight the effect of climate on subgrade moisture content and the importance of defining appropriate design subgrade conditions, particularly for the weaker, more moisture-sensitive materials.

Pavement Materials

Material Selection: Despite the innumerable influences that exist, there are some dominant factors in pavement performance that can be identified in order to design and construct LVSRs in a wide range of environments with reasonable confidence. These dominant factors are:

- traffic loading (represented by the design ESAs)
- environment (represented by the Weinert N-value/rainfall)
- material properties (represented by the material's plastic modulus calculated by multiplying the PI by the percentage passing the 0.425mm sieve)
- pavement configuration (cross-section)

Material Characteristics: Table 5.9 summarises the characteristics of various material types that critically affect the way in which they can be incorporated into an appropriate pavement configuration in relation to their properties and the prevailing conditions of traffic, climate, economics and risk assessment.

Table 5.9 - Pavement material categories and relative characteristics

Parameter	Pavement Type			
	Unbound			Bound
	Unprocessed	Processed	Highly processed	Very highly processed
Material types	As-dug gravel	Screened gravel	Crushed rock	Stabilised gravel
Variability	High	——— Decreases ———		Low
Plastic Modulus	High	——— Decreases ———		Low
Development of shear strength	Cohesion and suction	Cohesion, suction and some particle interlock	Particle interlock	Particle interlock and chemical bonding
Susceptibility to moisture	High	——— Decreases ———		Low
Design philosophy	Material strength maintained only in a dry state	Selection criteria reduces volume of moisture sensitive, soft and poorly graded gravels		Material strength maintained even in wetter state
Appropriate use	Low traffic loading in very dry environment	Traffic loading increases, environment becomes wetter		High traffic loading in wetter environments
Cost	Low	Increases	High	High
Maintenance reliability	High	——— Decreases ———		Low

Depending on the climatic environment, naturally occurring pavement materials may need to be brought near to saturation moisture content for efficient compaction, but it is imperative that they be allowed to dry back to at least equilibrium moisture content before sealing. Specifications will be necessary to ensure that premature sealing does not lock in construction moisture.

Pavement Configuration

As highlighted above, pavement configuration is influenced by the properties of the materials being utilized and by water on their performance. Thus, attention to detail in drainage design and construction is essential for optimum performance. Based on the broad material categories and their characteristics, as summarized in Table 5.9, pavement configurations have been developed for the following three zones:

Zone A Configuration: The principal features of the Zone A environment are relatively low traffic, a dry climatic environment and materials which are highly dependent on soil suction and cohesive forces for development of shear resistance. These forces may well be the only source of shear strength in these relatively weak materials because a deficiency of durable stone prevents reliance on inter-particle friction. Thus, even modest levels of moisture (> 60% saturation) are enough to reduce confining forces sufficiently to cause distress and failure.

Use of sealed shoulders will maintain the zone of seasonal moisture variation outside of the outer wheel track.

Good external drainage can be achieved with a raised embankment and provision of sufficiently deep side drains, i.e. increasing crown height.

Satisfactory performance with the use of Zone A materials can only be achieved whilst the pavement remains in a relatively dry, stiff condition, (i.e< 80% of OMC). Achievement of this state depends on the success of design features used to inhibit excess moisture movement into the pavement layer from the shoulders and from the embankment beneath the pavement. This can be achieved by such measures as sealing the shoulders, as illustrated in Figure 5.17, or by using unsealed shoulders, relatively low permeability if they do not otherwise impede internal drainage (Section 6.7).

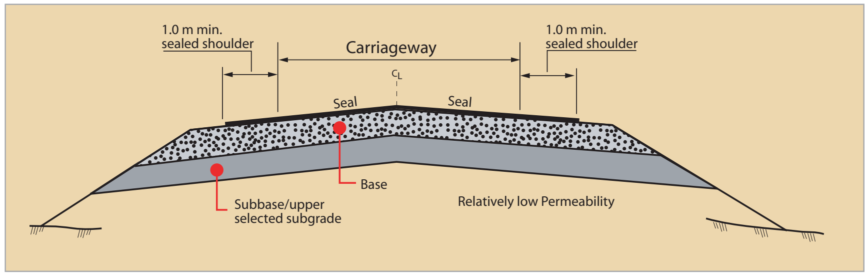


Figure 5.17 - Pavement configuration for Zone A materials (unprocessed, unbound materials)

Zone B Configuration: The principal features of Zone B are low to medium traffic, a dry to moderate climatic environment and materials that have a moderate dependency on all forms of shear resistance - friction, suction forces and cohesion. Because of the moderate strength potential of such materials, concentrations of moisture in the range 60% - 80% saturation may be enough to reduce the strength contribution from suction or cohesion sufficiently to cause distress and failure[33]. Because of the variable nature of these materials and their poor internal drainage, emphasis is best placed, on keeping moisture away from the pavement system by sealing shoulders, as well as on using pavement materials that can provide a frictional component of shear strength.

Zone C Configuration: The principal features of Zone C are medium to high traffic, a moderate to wet climatic environment with materials that have a minor dependency on suction forces and cohesion and rely either on:

(a) internal friction which is maximized when the aggregate is hard, durable and well-graded (granular, unbound materials), or

(b) physico-chemical forces which are not directly affected by water (bound, granular materials)

Very high levels of saturation (80% - 100%) will cause distress which will usually result from pore pressure effects under wheel loads and mobilization of plasticity in the fine fractions[33]. To avoid this situation, various positive design features are required including:

- sealed shoulders
- use of low-permeability selected lower subbase to protect the subgrade from moisture movements
- a subbase layer to be at least as permeable as the base layer, free to discharge into deep side drains

5.4.4 Design Process

External Factors

A number of factors, which are often of a non-technical nature, can have a significant influence on the pavement design process. These factors (political, social, institutional, etc.), were discussed in Chapter 3 and are not repeated here.

Structural Design

Over the past 25 years several methods of pavement design have been developed in southern Africa based on both mechanistic and empirical methods. In addition, several methods have also been imported and adapted from overseas practice for use in the region.

Mechanistic/Analytical Methods: Mechanistic methods are derived from laboratory studies of the mechanical behaviour of the pavement, in which materials are exposed to measured stresses and strains. A suitable theory to compute the stresses and strains in the actual pavement is then used, together with a transfer function (or calibration factor), that relates the mechanical response obtained from the laboratory studies to the actual behaviour of the real pavement.

Mechanistic/analytical design methods require a considerable amount of material testing and computational effort before they can be properly used. Moreover, their application to higly variable, naturally occurring materials, which make up the bulk of LVSR pavements, is questionable and they are very poor at simulating environmental deterioration and therefore not well suited to LVSRs.

The South African Mechanistic Design Method (SAMDM)[34], which is based on a linear elastic model, and the Elasto-Plastic Design Method (S-N method), based on a non-linear elastic model, are examples of mechanistic methods used in the SADC region for pavement design. These methods have been used in South Africa in the preparation of simplified design manuals such as a catalogue of structures in which the materials commonly available in the region have been tested and the results used to prepare thickness designs[35].

Empirical Methods: Empirical methods are derived from empirical studies of pavement performance in which the design is based on past successful practice. Empirically based methods are likely to be satisfactory, provided the materials, environment and conditions of loading do not differ significantly from those which applied during the original empirical studies on which the designs were based. Thus, the extension of empirical methods to different loadings, different materials and different environmental conditions can be achieved only by carrying out expensive and time-consuming full-scale pavement experiments.

Empirically based methods have been used in the preparation of a number of simplified design catalogues of structures in the SADC region, such as the commonly used TRL ORN 31 (1993)[27] and the DCP Design catalogue[36].

Appropriateness of Design Methods: Ideally, an appropriate pavement design method should be based on experience and fundamental theory of structural and material behaviour developed over time. It should also take account of local conditions of climate, traffic, available local materials and other environmental factors. It should thus allow the designer to produce an appropriate pavement structure of sufficient bearing capacity to carry the anticipated traffic over its design life at a pre-determined terminal level of service.

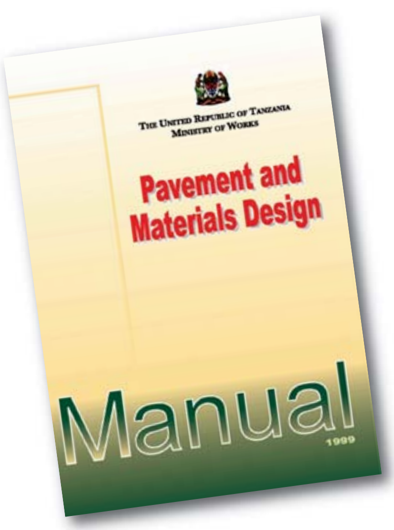
The following factors provide a benchmark against which the appropriateness of current design methods may be evaluated for application to LVSRs:

- subgrade design classes: These should be narrow enough to take advantage of the range of strong subgrade materials which predominate over extensive parts of the region
- design traffic classes: These should be relatively narrow to cater incrementally for design traffic loadings in the range up to 500,000 ESA
- materials classes: There should be a sufficient number of classes to cater for the full range and differing properties of naturally occurring residual weathered rocks (e.g. granite, quartzite) and pedocretes (e.g. calcrete, ferricrete) that occur extensively in the region
- materials specifications: These should be based on proven field performance in relation to such factors as traffic, subgrade design class, sealed surface design and geo-climatic zone

Based on the above criteria, the various design methods generally used in the SADC region were assessed for their applicability to low-volume roads. Those mentioned in Table 5.10 were generally found to be suitable, with the proviso that they be used flexibly rather than prescriptively.

Table 5.10 - Pavement design methods appropriate for use in the SADC region

Mechanistic-Empirical Methods	Empirical Methods
S-N Method (1993)[37]	DCP Method (1984)[36]
TRH4 (1996)[35]	SATCC Pavement Design Guide (1997)[38]
	TRL ORN 31 (1993)[27]
	TRL/SADC Pavement Design Guide (1999)[17]



In addition to the above generic methods of pavement design methods, there are a number of other country specific guides/manuals which have been developed within a few countries in the region. The most prominent ones are:

- Zimbabwe Pavement Design Guide (1975)[39].
- Botswana Roads Design Manual (1982)[40].
- Tanzania Pavement and Materials Design Manual (1999)[41].

None of the above methods are directly comparable, except on a case by case basis, because they differ with regard to a number of details such as the range of traffic and subgrade design classes, design subgrade strength (soaked versus in situ moisture content) etc. In this regard, some methods are more conservative than others. Nonetheless, they are all based on research/investigation work carried out in the region specifically for application to low-volume roads.

The designer should become fully conversant with the details of each of the recommended methods listed above before adopting any particular one in their area of the SADC region. These methods are fully documented in the literature.

A brief resumé of the generic design methods is given below:

S-N Pavement Design Method (1993): The S-N (Elasto-Plastic) design method is a mechanistic method based on the elastoplastic behaviour of granular pavement materials and bituminous surfacings. It uses non-linear analysis to model the pavement together with empirically derived transfer functions calibrated with HVS testing to predict the plastic deformation (rutting) in the granular layers. This approach has provided the basis for the development of a catalogue of pavement structures catering specifically for low-volume roads.

TRH4 (1996): The TRH4 design method is based on the South African Mechanistic Design Method which uses linear elastic analysis to model the pavement in which the stresses and strains that are most likely to initiate failure in a particular material type have been related to traffic load, via appropriate transfer functions, some of which were calibrated from HVS testing.

Dynamic Cone Penetrometer (DCP) Method: The DCP design method is an empirical method developed in South Africa, that uses the in situ measured bearing capacities of existing pavements, correlating them with HVS tests on similar material and pavement types.

SATCC Pavement Design Guide (1997): The SATCC Pavement Design Guide provides a catalogue of pavement structures that were developed through a desk study of practice deemed appropriate to the region, primarily as exemplified by TRL Overseas Road Note 31 (1993) and the TRH4 (1996).

TRL ORN 31 (1993): This guide is based on research and experience in over 30 countries mainly tropical and sub-tropical. Previous editions have been used for the design of LVSRs worldwide. The latest (1993) edition covers a wider range of materials and structures with a catalogue of designs that cater for traffic up to 30 million standard axles.

TRL/SADC Pavement Design Guide (1999): This guide is based on the monitoring and testing of selected sections of road on the existing networks in Botswana, Malawi, Zambia and Zimbabwe to enable designs to be evaluated. The research focused on measuring how road pavements performed with time and traffic and in different climatic conditions. It also identified features which need to be included in the road design to minimize risk, including environmental influences, the performance of "non-standard" materials and actual modes of deterioration. The output of the research programme was the development of a set of new structural design charts and a materials design procedure for low-volume roads in the region, based on a wide range of traffic levels, design subgrade classes, materials types and geo-climatic zones.

Pavement Design Process: The main steps to be followed in carrying out a design for a LVSR pavement include:

- estimating the amount of traffic and the cumulative number of standard axles that will use the road over the selected design life
- assessing the strength of the subgrade soil over which the road is to be built
- selecting the most economical combination of pavement materials and layer thicknesses that will provide satisfactory service over the design life of the pavement

Although the above process may appear relatively simple and straight forward, there are a number of aspects pertaining to LVSRs which require careful consideration. These aspects are highlighted in the generic design process presented in Table 5.11.

Table 5.11 - Typical checklist of LVSR pavement design factors

Main Parameter	Influencing item	LVSR issue
Design philosophy	- level of service - design standard - interacting environments	- appropriate to LVSRs - use of appropriate standards - need to cater for external factors
Design strategy	- road function/classification - analysis period - design life - staged construction?	- can be primary, secondary or tertiary - short, medium, long? - short, medium, long? - implications on design
Design traffic	- type and count - axle loads - equivalence factors - power exponent - tyre pressures	- reliability of data - seasonality factors; growth projections - motorised and non-motorised - damage factors - impact of overloading - construction traffic - basis of choice - basis of choice (< 4?, > 4?) - impact; design counter-measures
Materials	- availability and type - selection strategy - moisture sensitivity - problem soils (e.g. expansive) - testing	- properties and impact on design - specifications and test methods - impact on design and pavement x-section - design counter-measures - appropriate test methods
Environment	- climatic region - moisture regime - temperature and humidity - modifying influences - climate (e.g. El Nino)	- arid/semi-arid, semi-arid/sub-tropical, sub-tropical/humid? - soaked, unsoaked, equilibrium moisture contents for design? - age hardening of bitumen, hydrogenesis - irrigation, vegetation, deforestation - long-term consideration
Practical considerations	- drainage and hydrology	- internal and external drainage - embankment height; crown height above drain invert level
Structural design	- pavement design method	- use of appropriate methods of design - sealed or unsealed shoulders
Cost analysis	- economic life-cycle cost analysis	- economic analysis methods (producer surplus, consumer surplus?) - evaluation tools (HDM4, RED, etc)

Cost Comparisons

In order to arrive at an optimum pavement design solution, a life-cycle cost analysis should be made of all potential design alternatives capable of providing the required level of service for the lowest cost over the analysis period.

The main economic factors which determine the cost of the pavement facility include:

- analysis period
- structural design period
- construction costs
- maintenance costs
- user costs
- discount rate

The life-cycle cost associated with a particular design alternative is illustrated in Figure 5.18.

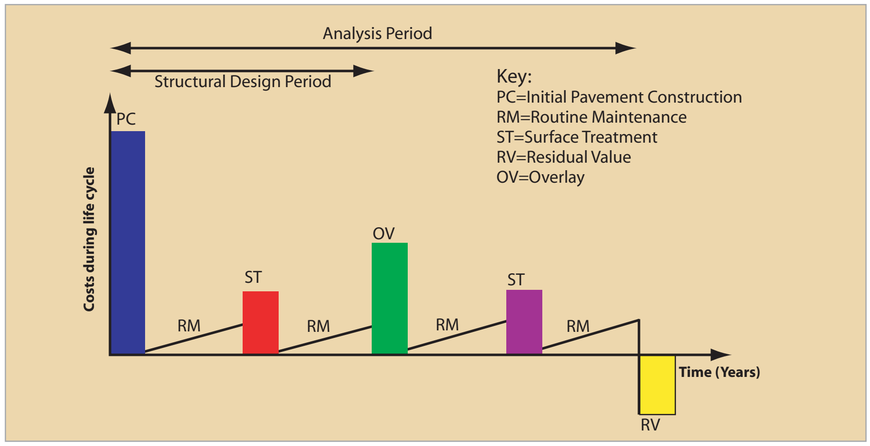


Figure 5.18 - Components of a typical life-cycle cost analysis

As indicated in Table 5.7, a relatively shorter design life is frequently used for low-volume roads. Moreover, user costs are not necessarily traffic related and, especially at the low end of the traffic spectrum, may well be manifested otherwise.

The optimum pavement design solution, which should be the design objective, is a balance between construction, maintenance and road user costs and, as illustrated in Figure 5.19, is very much traffic related[42]. Thus, the optimum structural capacity pavement for a LVSR might well incur lower initial construction costs but, within its life cycle, this would be balanced by higher maintenance and VOC. Conversely, a higher capacity pavement would incur higher initial construction costs but lower maintenance and VOC.

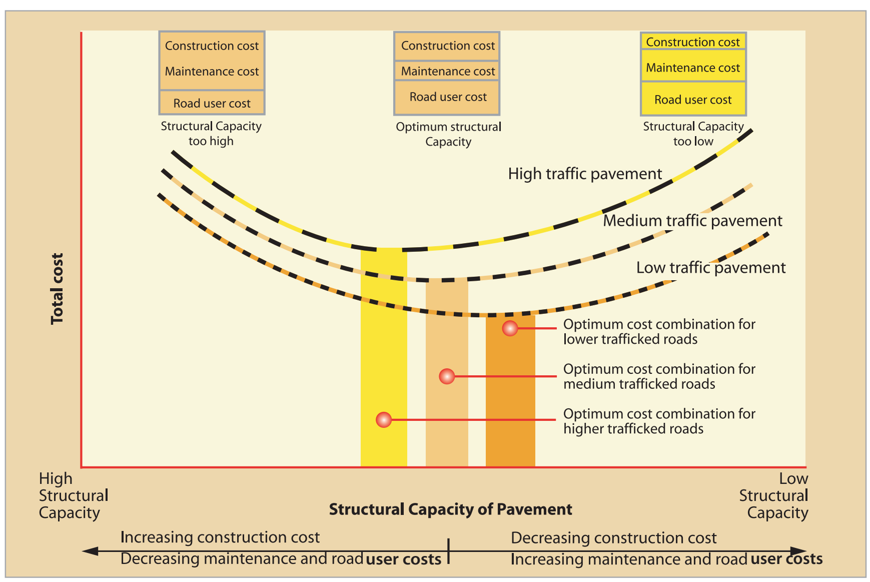


Figure 5.19 - Combined cost for various pavement structural capacities

5.4.5 Design Output

Selected Design

The cost analysis should be regarded as an aid to decision-making as it does not necessarily include all factors leading to a decision and should therefore not override all other considerations. These other considerations include the various exogenous factors discussed in Chapter 3, which are particularly important in the provision of low-volume roads.

Quantification and Mitigation of Risk

One of the major aspects concerning the use of marginal materials and thin pavement structures is the perceived increased risk of failure, particularly as regards the adverse impact of moisture on pavement performance. Thus, once the final design has been selected and pavement construction is undertaken, it is necessary to ensure that the critical design assumptions are incorporated into the pavement both during and after construction. These include:

- drainage provision
- material quality
- subgrade bearing capacity
- construction control
- overloading
- maintenance

Depending on circumstances, some of these factors will be more important than others. Generally, the risk of failure can be expected to increase if a number of factors are relaxed together. If one or the other of the design assumptions cannot be met due to some unforeseen constraint, it may be possible to adjust the overall design in a number of ways. For example, it may be feasible to reduce material standards but there might be a concomitant need to improve drainage and bearing capacity or, if design assumptions are not met in the lower pavement layers, it may be possible to adjust the overall design by using higher-strength upper layer materials or thicker courses in the upper parts of the pavement.

Ultimately, as with all road projects, control of construction quality, maintenance and overloading will ensure that the maximum benefits will be obtained from the recommended design.

Performance

Box 5.9 - Why do gravel road bases often perform better than predicted?

Many bituminous pavements constructed of natural gravels have performed exceptionally well despite extensive overloading (according to the 4^{th} power law) and poor maintenance. The following factors may explain this:

- reduced traffic loading (extended "life") due to inappropriate damage exponent
- good (strong) subgrade materials
- pavement design thickness based on unduly conservative saturated subgrade conditions
- predominantly dry environment
- stiffer pavement layers than anticipated at the design stage (base, subbase and subgrade)
- inappropriate materials specifications

The above uncertainties emphasise the need for developing local standards, specifications and pavement performance relationships.

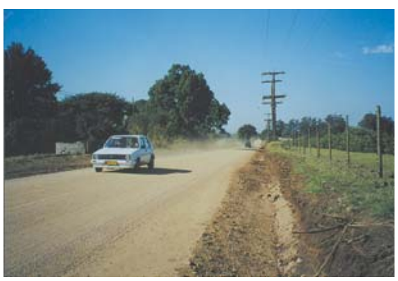
5.5 Surfacing

5.5.1 Introduction

As highlighted in this Guideline, gravel deposits in many SADC countries are not only a finite, non-renewable resource but, in many areas, are either non-existent or inaccessible. There is also an increasing awareness that, even at relatively low traffic volumes, the upgrading of unpaved roads to a sealed standard can be more cost-effective than maintaining the unpaved gravel road. As a result, the use of bituminous surface treatments over light pavement structures for the upgrading of a substantial length of gravel roads in the SADC region is expected to become more widespread.

There is a wide variety of bituminous surface treatments that can be used on LVSRs. In addition to the traditional *chip seal* there are a number of relatively little known "alternative surfacings" which, in appropriate circumstances, allow non-standard local materials to be judiciously used in situations where the use of conventional materials would be prohibitively expensive. There is also a range of labour-based bitumen surfacing techniques which, although still inadequately exploited, offer scope for providing beneficial employment to small contractors and local communities.

5.5.2 Objective


Typical gravel road.

The main objective of this section is to highlight the wide variety of bituminous surface treatment types that are available for use with LVSRs and to provide guidance on their selection in relation to a range of prevailing circumstances. In so doing, the section deals with the following aspects of surfacings for LVSRs:

- Role and Function of Surfacings.
- Types and Performance Characteristics.
- Constituents, Properties and Specifications.
- Selection of Surfacing Type.
- Surfacing Design.

5.5.3 Role and Function of Surfacings

Pavement surfacings fulfil a variety of functions which offer a number of advantages over unsealed roads. The characteristics of these functions are:

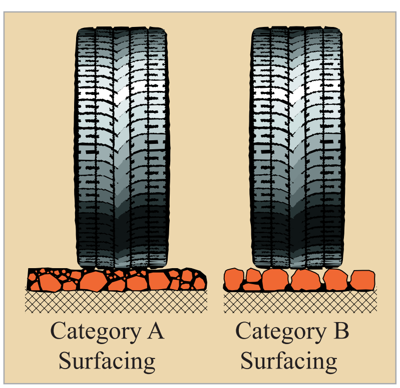
- seal and protect the base and provides strength at the road surface so that the latter can resist the abrasive and disruptive forces of traffic
- transmit to the base the vertical and horizontal forces imposed by moving traffic. Have no significant load-distributing properties
- protect the pavement from moisture ingress, thus preventing loss of pavement strength, thereby permitting the use of many materials that would otherwise not be appropriate
- improve safety by providing a superior skid-resistant surface, free from corrugations, dust and mud, often increasing light-reflecting characteristics and allowing the application of pavement markings
- prevent gravel loss, resulting in elimination of the costs of replacing gravel, a finite, non-renewable resource
- generate savings in vehicle operating costs due to improved riding quality and lower maintenance costs to maintain an acceptable level of service


Typical LVSR offering many advantages over an unsealed road. In certain circumstances a bituminous surfacing may be warranted at traffic levels of less than 100 vpd.

Sand seal surfacing.

Double chip seal.

Single Otta seal with sand seal cover.



The Cape seal is a hybrid type of seal falling between Category A and Category B type surfacings.

5.5.4 Types and Performance Characteristics

Surfacing types

Various types of bituminous surfacing are available for use on LVSRs in the SADC region. These are illustrated in Figure 5.20.

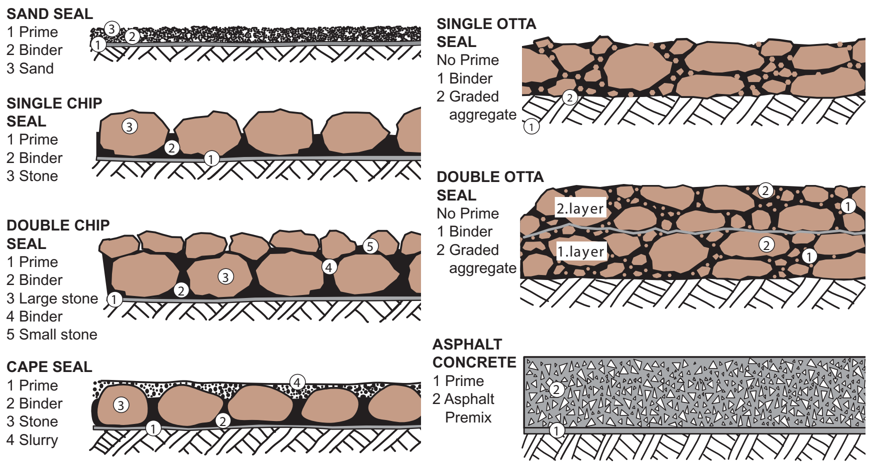


Figure 5.20 - Schematic common types of bituminous surface treatments

The above surfacing types offer a range of options and opportunities for addressing the particular challenge of providing appropriate, affordable and sustainable road surfacings. They have been developed to apply to specific situations relating to traffic volume and type, environment, pavement structures, material availability, etc. The challenge is to match the surfacing type to the prevailing circumstances in the most cost-effective and sustainable manner.

Mechanism of performance

The various bituminous surface treatments (excluding asphalt concrete) illustrated in Figure 5.20 may be placed in two categories as regards their mechanism of performance under traffic as follows:

Category A: (sand seal, slurry seal, Otta seal)

These seal types rely to varying extents on a combination of mechanical particle interlock and the binding effect of bitumen for their strength, similar to a bituminous premix. Early trafficking and/or heavy rolling is necessary to develop the relatively thick bitumen film around the particles. On this basis, the likelihood of stone becoming dislodged and whipped off the road by vehicles is relatively small.

Under trafficking, the seal acts as a stress-dispersing mat comprising of a bitumen/aggregate admixture - a mechanism of performance which is quite different from that of Category B surfacings.

Category B: (chip seal)

This seal type relies on the binder to "glue" the aggregate particles to the base, this being the primary objective of the binder. Where shoulder-to-shoulder contact between the stones occurs, some mechanical interlock is mobilized. Should the bitumen/aggregate bond be broken by traffic or poor adhesion, in-sufficient material strength, water ingress or numerous other causes, "whip off" of the aggregate by traffic is almost inevitable. Under trafficking, the aggregate is in direct contact with the tyre and requires relatively high resistance to crushing and abrasion to disperse the stresses without distress.

The mechanism of performance of slurry seals is similar to that of a very thin bituminous premix, which tends to harden relatively rapidly and become stiff and brittle. The behaviour of sand seals is similar to that of slurry seals but they tend to remain flexible for longer. As a result of the difference in the mechanism of performance under traffic between Category A and Category B, they also differ markedly with respect to such factors as material requirements, design approach, construction features. Examples of these differences are listed in Table 5.12.

Table 5.12 - Relative differences in required properties between surface treatment types on LVSRs

Parameter	Category A	Category B
Aggregate quality	Relaxed requirements in terms of strength, grading, particle shape, binder adhesion, dust content, etc. Allows extensive use to be made of natural gravels.	Stringent requirements in terms of strength, grading, particle shape, binder adhesion, dust content, etc. Allows limited use to be made of locally occurring natural gravel.
Binder type	Relatively soft (low viscosity) binders are required.	Relatively hard (high viscosity) binders are normally used.
Design	Empirical approach. Relies on guide-line and trial design on site. Amenable to design changes during construction.	Rational approach. Relies on confirm-atory trial on site. Not easily amenable to design changes during construction.
Construction	Not sensitive to standards of work-manship. Labour-based approaches relatively easy to undertake if desired.	Sensitive to standards of workman-ship. Labour-based approaches relatively easy to undertake if desired.
Durability of seal	Enhanced durability due to use of relatively soft binders and a dense seal matrix.	Reduced durability due to use of relatively hard binders and open seal matrix.

Performance Characteristics

The performance of a bituminous surfacing in terms of its life depends on a number of factors including:

- type of surfacing
- pavement structure (bearing capacity)
- traffic using the road
- environment
- road characteristics (geometry – curvature, gradient, camber, inter-sections, etc.)

Example of a double Otta seal (using de-composed granite) after 10 years in service in a harsh, semi-arid environment with practically no maintenance.

Experience in the SADC region has indicated the approximate ranges of lives for the different seal types given in Table 5.13. In addition to the factors listed above, seal life will also depend on such factors as aggregate quality, bitumen type and durability, and construction quality.

Table 5.13 - Expected service lives for some of the typical surface seals

Type of seal	Typical service life (years)
Sand seal	2 - 4
Slurry seal	2 - 6
Single chip seal	4 - 6
Double sand seal	6 - 9
Double chip seal	7 - 10
Single Otta seal plus sand seal	8 - 10
Cape Seal (13mm + single slurry)	8 - 10
Cape Seal (19mm + double slurry)	12 - 16
Double Otta seal	10 -14

5.5.5 Constituents, Properties and Specifications

The primary constituents of bituminous surface treatments are the aggregate and the bituminous binder, which together fulfil different functions, depending on the type of surfacing.

The operational characteristics of the Otta seal are such as to allow the use of as-dug natural gravel which can be screened, if necessary, to remove fines and oversize material.

Screened gravel used as surfacing aggregate in the Otta seal.

Aggregates

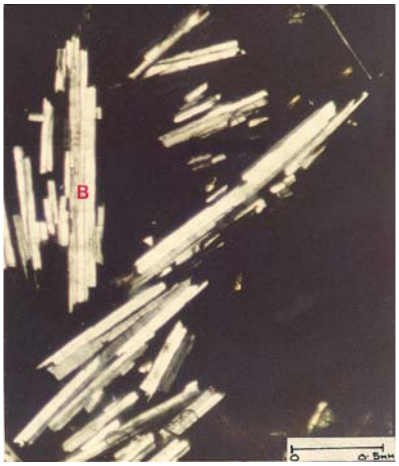
The main functions of the aggregate are to provide:

- adequate resistance to crushing and abrasion caused by moving wheel loads in order to transfer the tyre-induced stresses to the underlying pavement structure
- a skid-resistant surface in order to minimize skidding of vehicles, especially in wet weather
- a structure/matrix to accommodate the viscous and impervious binder
- protection to the binder from harmful ultra-violet radiation

The physical attributes which affect the performance of the aggregate in a surface treatment are related to their natural and processed properties, as indicated in Table 5.14.

Table 5.14 - Requirements for surfacing aggregates

Property	Requirements/implications on performance
Strength	• need for adequate resistance to avoid crushing and abrasion under traffic and consequent loss of stone, bleeding/flushing; • affected by particle shape, with cubical materials being stronger than flaky or elongated materials; • specification limits are placed in terms of: - Aggregate Crushing Value (ACV) - 10% Fines Aggregate Crushing Value (10% FACT) - Aggregate Impact Value (AIV) - Los Angeles Abrasion (LAA) - Texas Wet Ball Mill (TBM) - Flakiness Index (FI) • the greater the percentage of weak/soft particles, the higher the ACV, AIV, LAA or TBM values and the lower the 10% FACT
Durability	• need for adequate resistance to weathering to avoid crushing, loss of stone and bleeding/ flushing • related to weathering of material and alteration of primary minerals in the rock to secondary minerals (e.g. iron oxides, carbonates, clay minerals) • specification limits are placed in terms of: - wet/dry 10% FACT/ACV/AIV ratios - wet/dry 10% FACT/ACV/AIV ratios after 24 hour or 4 - day soaking in ethylene glycol - Durability Mill Index (DMI) test - Magnesium/Sodium Sulphate soundness test - Methylene Blue Value (MBV)
Adhesion	• need for good adherence to binder and non-susceptibility to stripping so as to prevent loss of aggregate/ravelling • aggregates containing acidic minerals (e.g. quartzite, granite) or very fine grained aggregates having smooth surfaces (e.g. silcretes or river gravels) tend to exhibit poor adhesion properties • adhesion problems can be overcome through use of cationic bitumen emulsionsand/or anti-stripping agents and/or pre-coating of aggregate • specification limits placed in terms of: - Riedel and Weber test. - Static Immersion test (Modified Vialit adhesion test). - Fines and dust content



Photomicrograph of fresh basalt unaltered plagioclase microphenocrysts.

Cubical chipings are essential for good particle interlock in Chip seals.

Water and binder absorption	● need for minimum absorption to avoid high binder absorption and loss of stone if not compensated in design ● related to water ingress and resulting decrease in strength/ durability of aggregate and susceptibility to stripping ● need to allow for binder absorption when using absorptive aggregates (e.g.calcrete) by increasing binder application rates and/or pre-coating ● specification limits are placed in terms of water absorption
Polishing	● need for good resistance to polishing in order to reduce scope for accidents due to skidding,especially in wet weather related to micro-texture of aggregate, which is a function of its mineralogy. Some aggregates (e.g. limestone) are more prone to polishing than others (e.g.dolerite) ● specification limits are placed in terms of the Polished Stone Value (PSV)
Mineralogical composition	● need for "fresh" durable aggregates as manifested by no/low secondary mineral content to avoid loss/breakdown of stone ● most secondary minerals are deleterious to the durability of aggregates and secondary mineral content is directly related to such properties as water absorption and indirectly to strength (e.g. 10% FACT) ● specification limits are placed in terms of the secondary mineral content
Organic matter	● need for aggregate to be free of contaminants so as to avoid poor binder adhesion and loss of stone cover ● related to material finer than 75 microns, which normally has high binder absorption ● no organic matter allowed in rocks
Grading	● need for control on grading and dust content for rational design purposes as well as to avoid problems with bitumen adhesion caused by dusty aggregates ● the use of larger single-sized stone in certain seals (e.g. chip seals) allows more latitude with binder application rate before voids are filled and flushing/bleeding becomes a problem ● specifications limits are placed on grading
Particle shape	● for some seals (e.g. chip seal) need for aggregate to be as cubical as possible for better particle interlock ● particle shape is strongly dependent on type of crusher (e.g. cone crushers tend to produce better particle shape than impact crushers) ● certain materials are prone to producing flaky material (e.g. silcrete, basalt) ● specification limits are placed on the Flakiness Index

Binders

The functions of the bituminous binder are to bind the aggregate particles together and to the underlying surface, as well as to provide a waterproof seal. The rheology of the binder allows it to deform and relieve stresses in the surfacing caused by deflections of the pavement. The binder should be capable of conforming to the deflections at the coldest conditions expected, otherwise cracking will occur. Once cracks have occurred, ingress of water will usually result in rapid degradation of the surfacing, particularly where moisture-sensitive materials are used in the construction of the pavement.

The durability of the bituminous binder is a key factor in the performance of surface treatments. Being a thermoplastic material, bitumen stiffens with a decrease in temperature and softens with an increase. With time, the binder in the seal hardens until it can no longer withstand the movement caused by diurnal temperature changes or flexure under heavy vehicles and cracking occurs, or until the bond between the cover aggregate and the binder fails and stone particles are displaced by traffic. The life of such a surfacing is thus critically dependent on the rate of the hardening of the binder and depends on the following factors:

- climatic regime (solar radiation, maximum and minimum temperature)
- binder film thickness
- intrinsic resistance of the binder to thermal oxidation hardening. This can be measured by the ARRB Durability test or by the Rolling Thin Film Oven test (RTFOT)

In areas where low temperatures are experienced the binder may become sufficiently hard during cold periods for the surfacing to become distressed. On the other hand, if the same surfacing is in an area with a mild climate, then distress will not occur until the binder has aged. Thus, the hardness level at which seals first show signs of distress (as indicated by viscosity measured at 45^{O}C) will vary with climate.

Figure 5.21 shows the relationship between bitumen hardening and seal life for bitumen of a given durability in an environment (Australia) which is very similar in many respects to that of the SADC region. This relationship shows the significant effect of temperature on the ageing/hardening of bitumens. A 5^{O}C difference in the yearly mean of daily maximum and minimum air temperatures causes a halving of seal life. Since the rate of ageing/hardening is dependent on the durability of a binder, every effort should be made to use bitumens with the highest levels of durability.

The ARRB Durability Test[43]

The ARRB Durability test measures the intrinsic resistance of a bitumen to thermal oxidation hardening. In the test, a 20 micron film of bitumen is deposited onto the walls of glass bottles and these are exposed in a special oven at 100 ^{O}C. Bottles are then withdrawn periodically, the bitumen is removed and its viscosity measured at 45 ^{O}C. The durability of the bitumen, is the time in days for it to reach an apparent viscosity of 5.7 log Pa.s (distress viscosity).

The ARRB durability test has been used in Australia since the mid 1970s for measuring bitumen durability. Most Australian State Road Authorities specify a minimum durability requirement for their bitumen. This test or the RTFOT is certainly worthy of wider use in the SADC region in order to engender a keener appreciation of the quality of the bitumens being used and of the effect of bitumen durability on seal life.

Cape seals and single or double Otta seals with a sand seal cover, are generally less susceptible to ageing and surface cracking than conventional chip seals as indicated in the empirical data in Table 5.13. The close textured surface provided by the graded aggregate in Otta seals, together with the sand seal or the rich slurry (in Cape seals), offer a higher degree of protection to the binder in the underlying layers than is provided by the second seal in the more open-textured chip seals.

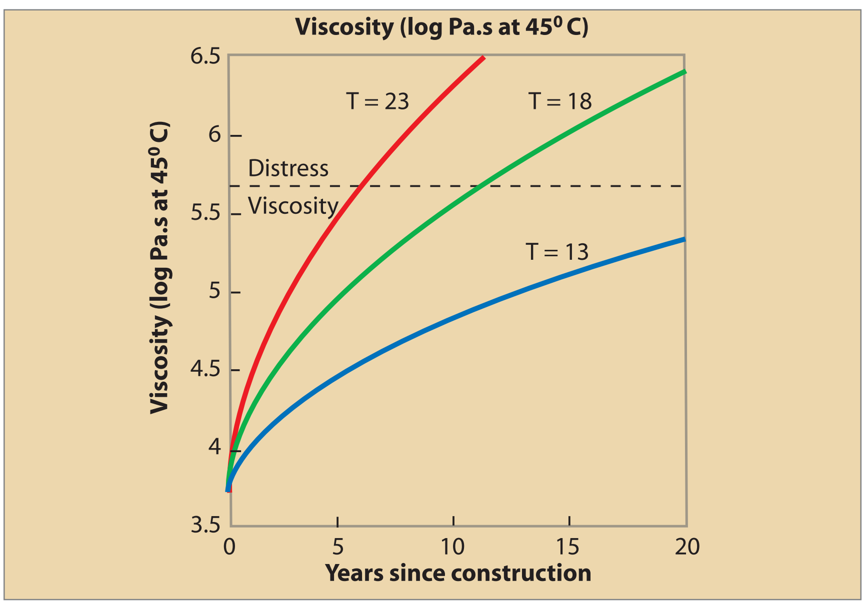


Figure 5.21 - Bitumen hardening graph for bitumen of a given durability[44]

The model illustrated in Figure 5.21 takes the following form:

$\text{Log}\ \eta = 0.476TY^{0.5} - 0.0227DY^{0.5} + 3.59$ (Pearson multiple correlation = 0.93)
(Standard error of estimate of log η = 0.19)

Where: η = the viscosity of the bitumen recovered from the sprayed seal (Pa.s at 45°C)
T = average temperature of the site calculated from the equation
D = ARRB Durability Test result (days)
Y = number of years since the seal was constructed
$T = (T_{max} + T_{min})/2$ (T_{max} = yearly mean of daily maximum air temperature (°C)
(T_{min} = yearly mean of daily minimum air temperature (°C)

Commonly used binders: The following types of bituminous binders are in common use in the region:

- *Penetration grade:* 80/100 or 150/200 penetration grade is normally used in most surface treatments, except in Otta seals which require softer grades, usually in the form of cutback bitumens.

- As a general guide, the viscosity of penetration grade binders is chosen with regard to the prevailing temperatures during construction and the stability under traffic. Harder (high viscosity) grades are more difficult to use but may be necessary to cater for heavy traffic in high ambient temperatures.

- *Cutback bitumen:* MC 3000 and MC 800 are commonly used, mostly in colder climates, where a relatively low viscosity binder is required to coat fine-grained aggregates (e.g. in an Otta seal), or damp aggregates, or to improve binder/aggregate adhesion. MC30 and MC 70 are used as a prime coat.

- Cut-back bitumens are produced by diluting a penetration grade binder with the appropriate "cutter" to achieve the desired characteristics. After construction, the diluents evaporate with time and the binder reverts back to its original penetration grade.

- *Bitumen emulsion:* Both anionic and cationic emulsions with high bitumen content (>60%) are used in most surface treatments and in a diluted form for the rejuvenation of surface treatments or in situations where it is not possible to use high cutter concentrations.

- *Tar:* This is known for its good adhesive and coating properties and good resistance to stripping by the action of water. However, certain tars (coke oven rather than gasifier) are no longer in common use because of potential environmental disadvantages. Low-viscosity 3/12 EVT tar is used as a prime coat.

- *Modified bitumen:* Binders modified with rubber or with other constituents generally exhibit improved durability properties and are generally used in special circumstances, such as in very aggressive climatic (extreme temperature) environments.

Recommendations on the use of the above binders and the related safety aspects are covered in various SABITA manuals.

Health aspects of foamed tar[45]

Tar is often perceived to be carcinogenic in all forms without considering the manner in which the constituents of the tar are produced.

The two main methods of tar production are pyrolysis of coal, which forms coke oven tar, and the Lurgi process, which produces gasifier tar.

Those components of tar which are believed to be carcinogenic are released to the atmosphere only at temperatures >360 °C. At that temperature, the harmful carcinogens are prevalent in coke oven tar but practically insignificant in gasifier tar. Thus, cold-placed foamed tar is a safe, viable construction material for stabilisation of sub-standard pavement materials.

Specifications

Specifications for surfacing aggregates vary from country to country in the region both in the type of specifications and in the applied limits of similar test methods. Table 5.15 gives the specification limits for various aggregate tests for a representative selection of SADC and other countries. Some countries place more demanding limits than others and some countries qualify their specifications by traffic and others do not.

Table 5.15 - Some specifications for surfacing aggregates

Test Property	Botswana	South Africa	Zimbabwe (Traffic)	Australia (Traffic)
	-	-	(< 2x10^6 ESA)	(AADT < 300)
10% FACT (kN) - Dry - Wet/Dry ratio	 > 210 > 0.75	 > 210 > 0.75	 > 120 > 0.65	 > 135 > 0.60
Max. LAA (%)	-	-	35 25	-
Max. FI (%)	30	30	30	35
TBM Value	-	-	-	< 30
Unsound Stone Content (%)	-	-	-	8
Adhesion (R&W)*	< 1	-	-	< 2
Max(%) Sodium or magnesium sulphate soundness	-	-	20	12

* The scales used to describe the degree of stripping vary between countries.

Aggregate fitness for purpose

Example of a 10 year old crushed coral stone surfacing aggregate which does not meet traditional strength and durability criteria but, nonetheless, has performed very satisfactorily in a LVSR situation.

Box 5.10 - How appropriate are existing aggregate specifications?

Most existing national aggregate specifications are "blanket type" specifications covering materials for all categories of roads. They suffer from a number of shortcomings including:

- They are seldom traffic related and often rule out the use of non-standard aggregates. For example, a material that is marginal in terms of strength may fail when carrying high traffic volumes on a main road with a high percentages of heavy vehicles, but may perform very satisfactorily in a low-volume rural road situation.
- They do not take into account the differing mechanisms of performance of the different seal types. For example, a strong, cubically shaped aggregate with a low flakiness index may be critical for the satisfactory performance of a chip seal but much less so for an Otta seal.
- The basis of derivation of some specifications, e.g. the minimum 10% FACT value of 210 kN, as employed in a number of countries, seems to be related to the traditional use of steel-wheeled rollers to embed the chippings and the related need for aggregate with a relatively high crushing strength. However, the current, common use of pneumatic-tyred rollers for this purpose does not require aggregates with such high crushing strength, yet the limits remain the same as before.

The above examples indicate that in many instances traditional aggregate specifications are inappropriate for use with LVSRs and that there is considerable scope for relaxing them on the basis of experience and research evidence. Ultimately, the challenge is to fit the materials available to an appropriate seal type and design rather than vice versa.

Proposed Revision to Specifications
Revisions to the specifications for the commonly used chip seal are proposed and are given in Table 5.16. These are based on a review of international specifications, notably in Australia and New Zealand, as well as on experimental evidence and experience of the performance of surfacing aggregates in the SADC region. Specifications for Otta seals are included for comparison.

Table 5.16 - Recommended revisions to chip seal specifications for LVSRs

Property	Design limits		
	Chip Seals		Otta Seals[1]
	Current	Proposed	
Strength 10% FACT (kN)	≥ 210	≥ 180 (>500 vpd) ≥ 150 (100-500 vpd) ≥ 120 (<100 vpd)	≥ 110 (> 100 vpd) ≥ 90 (<100 vpd)
Grading	As typically specified	As typically specified	Wide grading
Durability Wet/dry 10% FACT	≥ 75%	≥ 65%	≥ 75% (> 100 vpd) ≥ 65% (< 100 vpd)
Flakiness Index (%) 19.0 – 13.2 mm 9.5 – 6.7 mm	 ≤ 25 ≤ 30	 ≤ 35 ≤ 35	If crushed material used, ≤ 35 (weighted on 4.75 to 13.2 mm fractions)
Adhesion	R & W ≥ 3	No relaxation. Precoat if R & W <3	
Water Absorption	-	≤ 5	Spray rate adjusted
Polished Stone Value	-	≤ 50 (> 500 vpd) ≤ 45 (< 500 vpd)	

1 – Otta Seal specifications should comply with the Botswana Roads Department Guideline No. 1.

5.5.6 Selection of Surfacing Type

Factors affecting choice

The choice of the appropriate surfacing type in a given situation will depend on the relevance of a number of factors, including the following:

- traffic (volume and type)
- pavement (type - strength and flexural properties)
- materials (type and quality)
- environment (climate - temperature, rainfall, etc.)
- operational characteristics (geometry - gradient, curvature, etc.)
- safety (skid resistance - surface texture, etc.)
- construction (techniques and contractor experience)
- maintenance (capacity and reliability)
- economic and financial factors (available funding, life-cycle costs, etc.)
- other (external factors)

Traffic volume and type: Practically any type of seal will be appropriate for low traffic situations, i.e. less than 750 equivalent light vehicles (elv)/lane/day. However, at very low levels (<250 elv/lane/day), lack of traffic moulding of the binder will result in relatively faster degradation of the seal, mostly through drying and oxidation of the binder, with the development of shrinkage cracking. In such a situation, early rejuvenation of the seal may be required to retain the stone under traffic.

Traffic volume for surfacing selection and design purposes is often expressed as the number of "equivalent light vehicles" (elv) per day. This is equal to the sum of the number of light vehicles and 40 times the number of heavy vehicles.

The use of sand and slurry seals is generally not recommended for traffic levels of more than about 2000 elv/lane/day as they tend to "bleed" quickly and eventually break up. At traffic in excess of 5000 elv/lane/day, the use of a combination of a single chip and sand seal is also risky.

Heavy braking and tight cornering situations require an appropriate choice of high stability surfacings. Asphaltic concrete and possibly Cape or double Otta seals are preferred to sand, slurry, chip or single Otta seals.

Where high percentages of heavy vehicles (particularly those with tandem and tridem axles) and/or harsh traffic actions (e.g. heavy braking and tight cornering) are likely, the use of sand, slurry and single seals should be avoided. In such situations, asphaltic concrete, or a double chip, Cape or Otta seal is preferable.

Type of pavement: An evaluation of the performance of various types of seals types constructed on light pavement structures in southern Africa has revealed that seal life was very dependent on the stiffness of the pavement[46]. The stiffer the pavement structure, the longer the life of the pavement before cracking. Deflection or "radius of curvature" measurements give an indication of the likely effects on seal life (Figure 5.22). Since surface deflection is directly related to the elastic modulus of the underlying pavement layers which, in turn, depends on in situ density then, ***where feasible, every effort should be made to compact the pavement layers of LVSRs to the highest density practicable - i.e. "compaction to refusal"*** (see Section 6.4.1).

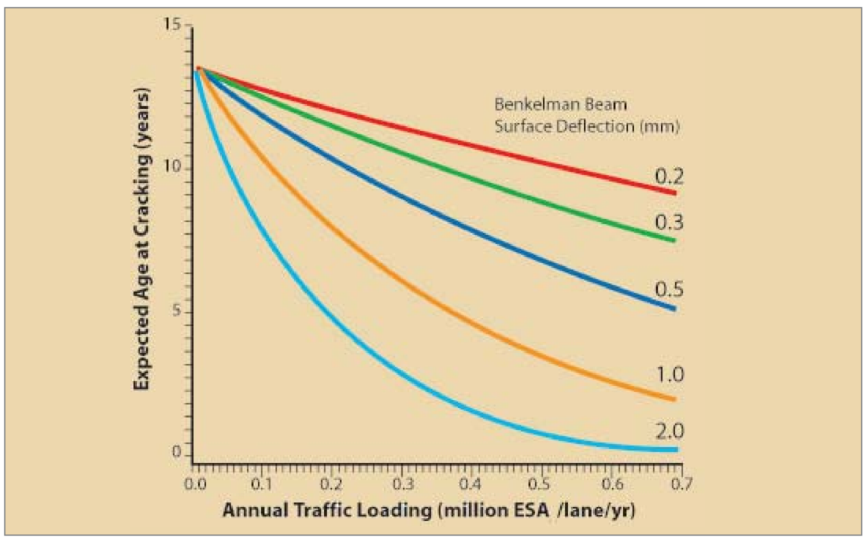


Figure 5.22 - Effect of surface deflection on seal life[46]

In situations on LVSRs, where weak subgrades occur (e.g. in expansive or soft clay areas) or where seasonal moisture variations are high (leading to relatively high deflections in the wet season), then the seal types which are more tolerant of relatively high deflections should be selected for use. For example, Otta seals or chip seals with appropriate modified binders are more tolerant of high deflections than others (e.g. slurry seals, Cape seals).

Bleeding due to embedment of surfacing aggregate in base.

A uniform, defect-free surface in the underlying layer is also required to avoid local distress in the seal. For example, soft bases will result in embedment of surfacing aggregate leading to loss of skid resistance and possible bleeding. This problem can be mitigated to some extent by the use of a low viscosity prime which will penetrate and strengthen the upper layer of the base and, thus reduce embedment of the aggregate. In contrast, very hard bases could result in breakdown of soft surfacing aggregate during rolling. To reduce the severity of this problem rubber-tyred pneumatic rollers, rather than steelwheeled rollers, should be used.

Materials: The type of aggregate available for use in a surface treatment has a major impact on the selection of the seal type. Where traditional aggregates are available within an economic haul distance, they lend themselves to use in conventional seals (e.g. slurry seals, chip seals, Cape seals). Conversely, where such aggregates are not available, then recourse to the use of more marginal aggregates in terms of, for example, strength or shape, is quite feasible with graded aggregate seals, such as the Otta seal. Table 5.17 indicates the types of seal that are best suited to various aggregates with marginal properties.

Table 5.17 - Seal selection based on marginal properties

Marginal Property	Recommended seals	Inappropriate seals
Grading	Otta, sand	Slurry, chip, Cape
Strength	Otta, sand, slurry	Chip, Cape
Durability	Otta, sand, slurry, Cape	Chip, slurry
Shape	Otta, sand, slurry	Chip, Cape
Dustiness	Otta, sand	Chip, slurry
Water absorption	Otta, sand	Chip, slurry

Loss of second seal due to bitumen hardening and embrittlement.

Environment: Environmental conditions in terms of the exposure of the seal to solar (ultra-violet) radiation, particularly in high-temperature conditions, play a critical role in the performance of all seals. The thinner and more open-textured seals, such as sand, slurry and single chip seals are particularly prone to early degradation resulting from oxidation and consequent embrittlement of the binder and ravelling of the aggregate. In contrast, Otta seals (single plus sand seal or double) and Cape seals, are especially suited to high temperature conditions, owing to the close interlocking aggregate texture and sand or slurry cover that protects the underlying binder from exposure to solar radiation.

Operational characteristics: The geometry of the road alignment in terms of gradient and curvature can have an adverse impact on seal performance. On steep grades or tight curves, seals are subjected to significant tyre-induced horizontal stresses for which seals with adequate shear strength are required. In these circumstances, the use of asphaltic concrete might be appropriate and, to a lesser extent, double chip, Cape or Otta seals would be preferable to sand, slurry or single chip seals.

LBM

The slurry seal lends itself to construction by labour-based methods.

Safety: In areas such as intersections, sharp bends and steep grades, adequate surface texture may be required for safety reasons, particularly in high rainfall situations. In such situations, certain seals, such as chip seals and coarsely graded Otta seals, because of their better skid resistance properties, would be preferable to sand or slurry seals.

Construction: The construction technique employed will usually influence the selection of the types of seal. The plant available, use of labour-based techniques or small contractors will result in the selection of the types of seal suited to these conditions. Similarly, the experience of the contractor with specific types of seal can influence the quality of some seals (e.g. chip seals) to a considerably greater degree than with sand or Otta seals.

Maintenance: Where maintenance capacity is high, ravelling, potholes and cracks can be rapidly and effectively repaired using sand, slurry and Otta seals. However, where a time lapse between the development of defects and maintenance is likely, more resistant/thicker seals such as double Otta seals, double chip seals, Cape seals or even asphaltic concrete are recommended.

Special conditions: Where specific problem conditions occur, the seal selection must take this into account. For example, where there is a saline subgrade or where saline construction materials are involved, then a highly impermeable seal is required, such as a bitumen-rich double chip seal or a Cape Seal.

Costs: The cost of constructing bituminous seals can be a significant proportion of the overall cost of a pavement, particularly in remote areas where traffic is light and aggregate may have to be hauled over long distances.

In very broad terms, for a typical LVSR project with no unusual circumstances in terms of excessive hauls or very remote areas, coupled with competitive tendering, the cost of priming, aggregate, binder and construction together make up between 10 and 20 per cent of the total road construction cost. The relative costs of various seals compared with a double chip seal (1.0) are given in Table 5.18.

Table 5.18. - Relative construction costs of LVSR surfacings

Type of seal	Relative cost	
	With prime	Without prime
Sand seal	0.56	N/A
Slurry seal	0.85	N/A
Single chip seal	0.56	0.58
Double sand seal	0.90	0.70
Double chip seal	1.00	N/A
Single Otta seal plus sand seal	1.00	0.75
Cape seal (13mm + single slurry)	1.20	0.60
Cape seal (19mm + double slurry)	1.60	0.90
Double Otta seal	1.00	0.90

The final selection of the type of surfacing would depend on the outcome of a life-cycle cost analysis which combines the discounted unit costs of the following items during service life of the seals under consideration:

- construction
- maintenance
- road user costs
- fog spray
- reseals
- repainting of road markings
- cleaning/repair of reflectors

Suitability for use on LVSRs

The suitability of various types of surfacings for use on LVSRs, in terms of their efficiency and effectiveness in relation to the operational factors outlined above is summarized in Table 5.19.

Table 5.19 - Suitability of various surfacings for use on LVSRs

(Key: SS = sand seal, SlS = slurry seal, SCS = single chip seal, DCS = double chip seal, CS = Cape seal, SOS+SS = Single Otta seal + sand seal, DOS = double Otta seal, AC =asphaltic concrete)

Parameter	Degree	Type of surfacing							
		SS	SlS	SCS	DCS	CS	SOS+ SS	DOS	AC
Service life required	Short								
	Medium								
	Long								
Traffic level	Light								
	Medium								
	Heavy								
Impact of traffic turning action	Low								
	Medium								
	High								
Gradient	Mild								
	Moderate								
	Steep								
Material quality	Poor								
	Moderate								
	Good								
Pavement and base quality	Poor								
	Moderate								
	Good								
Suitability for labour-based methods									
Contractor experience/ capability	Low								
	Moderate								
	High								
Maintenance capability	Low								
	Moderate								
	High								

Key Suitable/ preferred; Less suitable/ not preferred; Not suitable/ not applicable

Whilst not exhaustive, the factors listed in Table 5.19 provide a basic format which can be adapted or developed to suit local conditions and subsequently used to assist in making a choice of surfacing options. These options can then be subjected to a life-cycle cost analysis and a final decision made with due regard to prevailing economic factors and the overall financial situation.

An example of a single Otta seal with a sand seal performing very satisfactorily after more than 13 years in service and without any surfacing maintenance in a harsh environment.

Box 5.11 - Advantages and disadvantages of Otta seals

Although the choice of surfacing will depend on the particular conditions prevailing on any particular project and, ultimately, a life-cycle cost analysis, the Otta seal merits particular mention. This relatively new type of seal has been found to be particularly advantageous in situations where the following factors play an important role:

- road construction in remote areas where, for example, only natural gravels occur and where it may be prohibitively expensive to set up crushing facilities
- contractor capacity may be low and workmanship may be of indifferent quality
- flexibility and durability of the surfacing is required to tolerate, for example, comparatively low-quality, low-bearing capacity bases with relatively high deflections
- low maintenance capability
- high solar radiation resulting in an increased rate of weathering of the binder

The disadvantages of using Otta seals include the following:

- need to cater contractually for the post-construction "after care" of the seal
- blending of hot bitumen and cutting agents on site

5.5.7 Surfacing Design

The complexity of surfacing design depends very much on the type of seal involved. Some types of seals, such as chip seals and the Cape seal, entail a fairly complex, rational design process which involves selection of the appropriate aggregate size and calculation of the aggregate and bitumen spray rates, taking into account such factors as embedment of stone into the base or existing surface, gradient, climate, traffic speed, etc. Formulae and figures are available in the design manuals that allow these factors to be determined fairly easily.

In contrast to chip and Cape seals, Otta, sand and slurry seals are designed on the basis of broad guidelines and constructed by "feel" with the required ability of site personnel to adjust or correct the aggregate and binder application rates as a project proceeds or as the material quality varies.

The general aspects of seal design for the various surfacing types discussed above, except for the Otta seal, have all evolved from extensive South African and British practice as contained in the following documents:

- Draft TRH 3 (1996)[47].
- TRL - Overseas Road Note 3[48].
- SABITA Manual 10[49].

Until relatively recently, no formal guideline or manual existed for the design of Otta Seals. However, this short-coming has been rectified by the production of the following documents:

- Ministry of Works and Transport, Roads Department, Botswana:
  Guideline No. 1 - The Design, Construction and Maintenance of Otta Seals.
- Norwegian Public Roads Administration:
  Publication No. 93 - A Guide to the Use of Otta Seals.
- Ministry of Works, Tanzania:
  Pavement and Materials Design Manual - 1999.

The Otta Seal guideline contains detailed information on the design, construction, maintenance, specification and contractual aspects of Otta seals.

5.6 Summary

The key points arising in this chapter are:

1. The main factors affecting the performance of low-volume roads are traffic and environment, with the latter being more significant at low levels of traffic. Drainage in terms of the crown height is particularly important. Thus, measures that improve the pavement environment will significantly improve the performance of low-volume roads.

2. Examination of the origins of testing procedures and specifications for road-building materials often reveal that they emanated from very different environments and for levels of traffic different from those that prevail on low-volume roads in the SADC region. It is on the basis of these tests and specifications that many local materials are classified as "sub-standard" or "marginal" but which often perform much better than expected.

3. Measures that provide an improved (drier) road environment, such as sealing of shoulders and deepening of side drains, also enable locally available materials, previously considered unsuitable for road construction purposes to be used with greater confidence.

4. The materials available for road construction in much of the region are weaker than those generally found in Europe or the USA but subgrade soils tend to be stronger. Thus, strong subgrades and the generally drier prevailing environment facilitate the use of these "sub-standard" local materials in the upper pavement layers.

5. Pavement designs that are based on research in the region and include local environmental factors are now available. These designs are intended to make the best use of locally available materials without incurring unacceptable risk of failure. Familiarisation with local conditions and advice from local professionals will help to ensure that more appropriate designs can be implemented with confidence.

6. The traditional surfacing for sealing low-volume roads was a chip seal using a single sized stone with a high strength specification. Other options are now available that enable lower strength locally available aggregates to be used in designs that produce durable road surfacings.

7. Forecasts of vehicle loading and predicted damage to road pavements are usually based on the 4th power law. In dry environments, road pavements can be stiffer than usual and there is evidence to suggest that a lower exponent might be more applicable, thus reducing the effect of heavy vehicles by comparison with that of lighter ones.

This chapter has covered aspects of pavement design, materials and surfacing of LVSRs, which are subject areas in which substantial advances in knowledge have been made through research in the region. The judicious use of the recommended designs together with the appropriate construction methods covered in Chapter 6, will reduce sealed road construction costs and increase the provision of rural road infrastructure.

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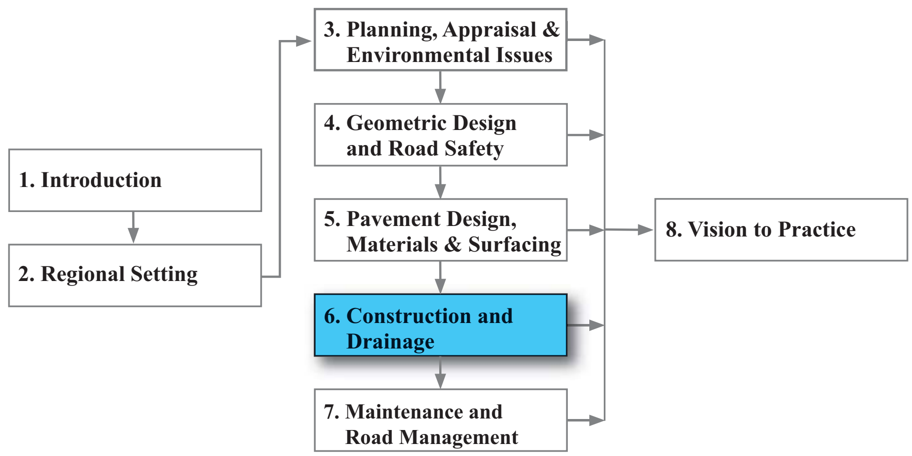
Chapter 6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Construction and Drainage

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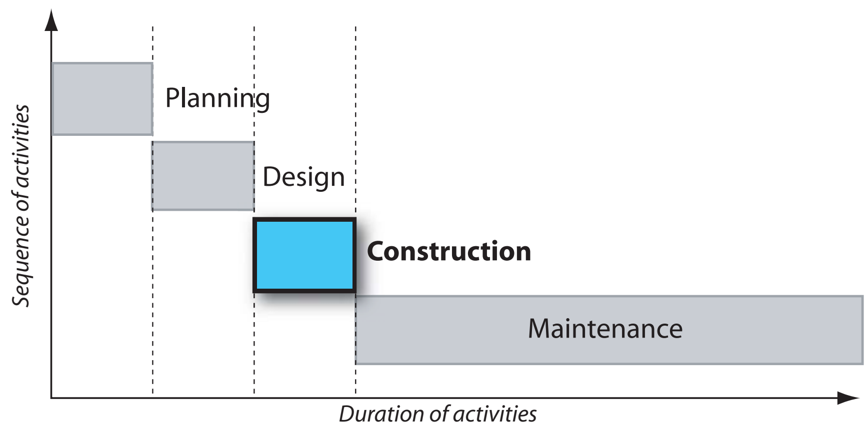
6.1 Introduction

6.1.1 Construction



Construction is a practical manifestation of the planning and design phases of LVSR provision in which the constructor faces the challenge of adopting a *construction strategy* that is appropriate to the prevailing social, economic, cultural and other needs of a particular country. In the SADC region, such a strategy should be aimed at optimising the use of limited funding by making maximum use of the relatively abundant resource of labour, indigenous materials and construction skills.

One of the secondary objectives and consequences of adopting an appropriate construction strategy is that it should reduce the demand for scarce foreign exchange, principally by reducing the need for plant-intensive operations, where feasible. This often requires modification of conventional construction management techniques, contract conditions, tender evaluation procedures, and the administration and financing procedures normally used for the construction of major, high-volume roads.

Irrespective of the construction strategy adopted, the quality of the construction process is critical as this can have a significant impact on the subsequent costs of maintaining the road. For example, *any initial savings made during construction through the inadequate provision of drainage or lax quality control are likely to paid for, many times over, during the life of the road through additional maintenance and road user costs.*

6.1.2 Drainage

Disruption of traffic and pedestrian movements due to flooding of rivers is a common problem in many rural areas.

Drainage is widely recognised as the single most important factor that controls the performance of any road, the more so a LVSR in which naturally occurring, often moisture sensitive, materials are used. The lack of good drainage can lead to ingress of water into the road structure, leading to structural damage and costly repairs and surface water can form a road safety hazard, especially on high-speed roads when it can cause aquaplaning. For these reasons, adequate attention to drainage is not only an important aspect of the preceding design process, but also of the construction and maintenance phases of road provision.

A clear distinction should be made between internal and external drainage. Internal drainage is concerned with controlling the movement of water within the road pavement or embankment, whereas external drainage is concerned with the control of surface water by various measures taken in the design and construction stages. In the final analysis, a balance has to be struck between the cost of the drainage measures and the function of the road as perceived by road users.

6.1.3 Purpose and Scope of Chapter

In view of the significance of labour-based methods in the construction of LVSRs, wherever this issue arises, it is indicated as follows: **LBM**

The main purpose of this chapter is to highlight the significant differences in approach to the construction of LVSRs by comparison with those of high volume, major highways. In view of the importance of utilising the most abundant resource in the region - labour - this chapter also seeks to raise awareness of the scope for utilising labour-based construction and of the type of equipment that is best suited to complement this approach. The importance of appropriate internal and external drainage is also highlighted as being of crucial importance in the performance of LVSRs.

6.2 Construction Issues

6.2.1 Characteristics of LVSRs

The construction *process* for LVSRs does not, in principle, differ from that used for other types of road. However, LVSRs are much more sensitive then other types of road to the social, economic and technical context in which they are built. Variations can be considerable with regard to the choice of construction method, type of resources available and type of construction materials being used. Moreover, aspects regarding social and environmental impacts, including the need for any resettlement action plan, require particular attention prior to the start of construction.

One aspect of the provision of LVSRs that is receiving increased attention is the use of labour-based construction. All the governments in the region recognise that economic growth and redistribution of wealth rely upon increased employment opportunities. Continuous efforts are therefore being made to create productive employment through the use of labour-based construction and maintenance, where these are technically and economically feasible.

6.2.2 Labour-Based Construction

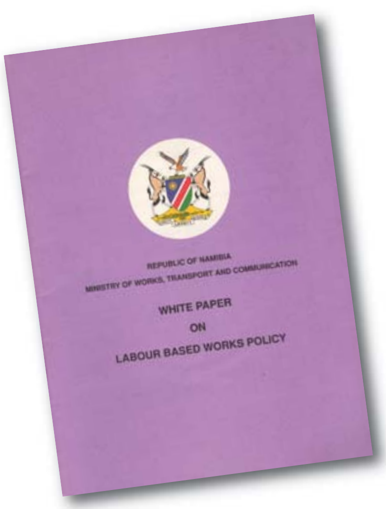
The objective of labour-based construction is to maximise the number of job opportunities per unit of expenditure. This approach involves using a combination of labour and light equipment rather than heavy plant, without compromising the quality of the end product. It optimises the use of labour and employs equipment only for those activities that are difficult for a labour force alone to undertake efficiently and cost-effectively. Unfortunately, despite the well-publicised and substantial potential benefits offered by labour-based construction, a number of myths and problems relating to this technology still persist in the minds of some practitioners.

Box 6.1 - Common misconceptions about the use of labour-based methods and small scale labour-based contractors[1]

Myths:
- standards should be lowered to allow for labour-based methods
- labour-based construction is out of date and incompatible with the modern world
- labour-based methods can be used for any construction activity
- labour-based construction is only intended for welfare relief schemes
- poorly educated contractors will never understand tender procedures
- voluntary labour can be used to keep costs down

Problems:
- lack of suitable documentation for the management of labour-based contracts
- many clients are still not open to even considering a labour-based approach for new projects
- many clients are unable to process payment for labour and materials fast enough to keep a labour-based contract operating smoothly

In order to overcome these problems, suitable forms of contract need to be more widely used; clients need to gain experience in awarding and managing labour-based contracts and small-scale contractors need to gain experience in managing such contracts efficiently. Government ministries also need to develop strategies that facilitate the implementation of pro-employment policies.



The development of a White Paper on Labour-based Works Policy is an example of a pro-active strategy by a SADC government to achieve increased utilization of abundant human resources in the roads sector[2].

Example of appropriate choice of technology

LBM

De-stumping of trees is an example of appropriate labour-based technology.

LBM

Screening of aggregate for road surfacing.

Before construction starts, all relevant environmental assessments should be completed to ensure that the project does not achieve its own goal at the expense of loss or inconvenience to non-beneficiaries or future generations [3].

Suitability of Construction Activities for Labour-Based Projects

Many activities are well suited to labour-based methods such as site clearance/bush clearing and ditch excavation wheneas activities, such as compaction of pavement layers or haulage of materials over long distances (typically > 5 km) are not. Quite apart from economic considerations, some construction activities (e.g. the manipulation of heavy precast sections) are just not possible without the help of the right machinery. However, these kinds of problem can be avoided if emphasis is given to those activities that can be undertaken effectively by labour-based methods, and design options selected that minimise the requirements for plant.

Labour-based projects usually employ a relatively large number of labourers. In such a situation, the site management staff should be particularly good "man-managers" with strong managerial and technical backgrounds. They should be familiar with local traditions and social structures in order to avoid serious disputes on site that could threaten the progress of construction and, ultimately, the sustainability of the project.

6.2.3 Environmental Considerations

Road construction can adversely affect the environment in a variety of ways. Assuming that the necessary mitigating measures have been incorporated in the contract documents, it is important that the contractor be made fully aware of his environmental responsibilities as part of his contractual obligations. Moreover, compliance with the environmental requirements of the project should be monitored throughout the construction process in order to correct problems before they occur (Section 3.4).

Box 6.2 - Typical best practice guidelines for environmental mitigation[3].

- **Construction process:** Ensure the existence of an Environmental Management Plan which sets out the specific undertakings for the necessary environmental protection responsibilities, measures, monitoring and auditing to be undertaken during construction in order to achieve the environmental requirements set out in the contract.

- **Construction procedures:** Ensure that procedures are adopted that:
  - minimise disturbance to flora and fauna
  - minimise sedimentation and erosion by implementing effective drainage/ stormwater control measures
  - minimise generation of dust and noise
  - progressively revegetate disturbed areas during road construction
  - minimise visual impacts and environmental disturbance at site camps
  - minimise environmental impacts of stockpiles and storage of materials
  - minimise construction wastes and dispose at an approved environmentally sustainable location
  - provide environmentally sound management for the handling, storage and disposal, if necessary, of fuel, oil, lubricants, bitumen and chemicals used in the road construction process

- **Auditing:** Ensure the existence of a documented environmental due diligence system to measure compliance with environmental management requirements throughout the construction process with the objective of correcting problems before adverse environmental impacts occur.

6.2.4 Mobilisation

Preliminary and General Items

LVSRs are often constructed in remote areas and establishment costs normally make up a substantial part of the total project cost. The cost of preliminary and general items, where establishment is included, is a larger proportion of total construction cost for LVSRs than that used on more heavily trafficked roads.

However, where labour-based methods are utilised, one can expect mobilisation costs to be considerably lower than these for large machine-based units. This favours the use of labour-based methods in remote locations, in circumstances where projects are relatively small or where larger projects can be split up into smaller contracts.

Health and Safety on Site

Road construction ranks among the most hazardous occupations in all countries of the world, particularly on projects where a large amount of labour is involved. The following typical LVSR site situations require that particular attention be paid to health and safety precautions on site:

- LVSRs are often constructed in remote areas where access to emergency medical care is limited, thereby aggravating the consequences in the case of accidents on site. Under these circumstances, greater awareness is needed of the risks attached to certain especially hazardous operations and appropriate measures should be taken to minimise these risks. For example, trained First Aid staff should be employed on site and an adequate stock of First Aid equipment and medicines should be kept in a secure clean place. This may, however, be a requirement under national employment law.
- Handling of hot bitumen is potentially harzardous due to the risk of burns and inhalation of fumes. The use of bitumen emulsion, which can be manufactured on site, is preferable[4].
- Traffic safety measures in remote areas with low traffic densities are often given less attention than they deserve. However, traffic moving through construction sites at high speed always poses a severe danger to construction staff.

Handling of bitumen is a hazard and requires suitable locations for storage, heating or blending.

HIV/AIDS

All governments in the SADC region are committed to combating HIV/AIDS. In this regard, construction operations are relevant on account of the following:

- Construction of roads requires the services of skilled personnel, depending on the type of operation and project. This leads to migration of labour and sometimes to the division of families, a situation that is widely considered to be a contributory factor in the spread of HIV/AIDS.
- LVSRs are often constructed in sparsely populated areas where the local communities are vulnerable to the transient effects of the influx of large numbers of workers. The establishment of a road camp may cause a rapid change in the local economy, which further exacerbates these effects.

Awareness and active involvement in taking measures to combat HIV/AIDS have become necessary requirements for sustainable operations and affect all responsible parties involved in road construction.

Counselling ahead of project commencement is an important measure to combat the spread of HIV/AIDS as a result of construction activities.

6.2.5 Contracts

Labour-Based works

The three main delivery mechanisms that may be adopted for expanding labour-based methods of construction and maintenance amongst small-scale contractors are shown in Figure 6.1 and are briefly described as follows[5]:

- *The Government-run Model:* In this model the responsibility for all aspects of contractor development (including small contract administration and payment) lies with the government roads agency.
- *The Agency Model:* Responsibility for all aspects of contractor development lies with an independent non-profit management agency or with a for-profit consulting firm.
- *The Development Team Model:* The responsibility is divided be between the employer, a construction manager and a materials manager.

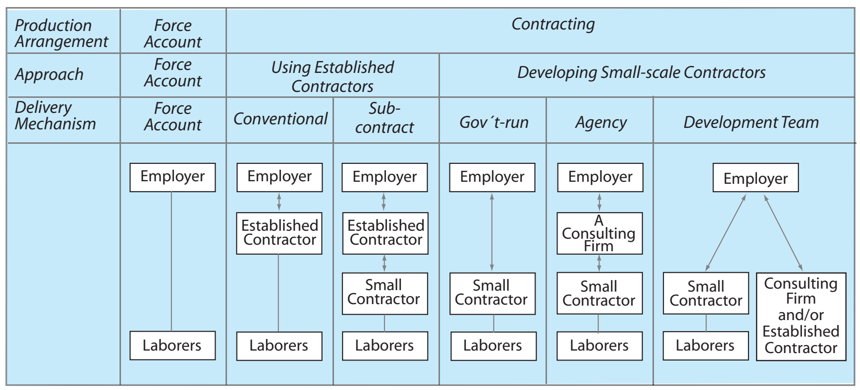


Figure 6.1 - Alternative arrangements for undertaking labour-based works

The type of model to be adopted will depend primarily on the country's contracting environment and on the extent to which the institutional reforms mentioned in Chapter 2 have been embraced. For example, if the roads agency is functioning well and reform can be facilitated, the Government run model may be the most appropriate. Conversely, if the roads agency is unable to effect the required reforms within a reasonable time, or would prefer to pass a portion of the risk of contractor development to the private sector, a Development Team Model may be the most suitable.

Risk Aspects

Wherever roads are constructed with innovative methods or marginal quality of materials, the aspect of risk inevitably plays a role in the process (Chapters: Pavement Design, Section 5.4.6). Risk needs to be carefully considered and managed in relation to the potential benefits offered. The roads agency is often in the best position to allocate risk as it sees fit as it is generally in control of the conditions that control the project.

The construction of LVSRs offers much scope for innovation and cost-savings as highlighted in every chapter of this Guideline. However, given the nature of the construction industry, the party most able to promote innovation is the roads agency. In so doing, *the agency cannot expect to reap the potential benefits of reduced construction cost that lie in the use of innovative methods unless it is also willing to carry a part of the any potential risks that may be perceived to be involved*.

A commercially operating contractor or consultant will have to price risk into a contract, involving insurance cost and potential losses in execution of the project if problems occur. This aspect is a common hindrance to innovations that would result in considerable benefits to society by providing LVSRs in rural areas using more cost-effective methods. It therefore appears reasonable that society, through the agency, also carries a large part of the calculated risk, bearing in mind that society is also the potential beneficiary in the use of innovative methods. Thus, the roads agency should carefully consider the merits of sharing some of the risk that normally lies with the contractor when allowing, encouraging or prescribing the use of methods or materials that are perceived to carry increased risk.

Planning and Design Stages

The key to ensuring optimal operations in construction with marginal materials and in a variety of different climatic conditions, lies in the preparation and planning/design of the contracts. Deriving maximum benefit from the use of marginal materials relies on the contractor's use of appropriate methods of winning the materials and subsequently processing them to meet the prescribed specification. The aim is to utilise the full potential of the material sources found in the project area once the appropriate standard has been set for the project. As illustrated in Box 6.3, incentives can be included in the conditions of contract to ensure that the contractor and the agency responsible for the project are both striving for the same end result.

Use of rock materials in bulk earthworks can speed up construction by:

- *Allowing thick layers to be constructed in a single lift.*
- *Eliminating the need for construction water and mixing in earthwork.*
- *Minimising the need for laboratory testing.*

Box 6.3 - Issues to consider during contract preparation

As contractors normally depend strongly on their cash flow to meet their financial obligations for the project, the following aspects should be given particular attention in the preparation of contracts for the construction of LVSRs:

- A contractor may be reluctant to stockpile materials well ahead of construction (an approach that improves the management of marginal materials), unless there is separate payment for borrow pit operations that secures his cash flow.
- Contractors are unlikely to select the better of two materials that both meet minimum quality requirements if they have to carry the entire amount of any additional cost incurred.
- The inclusion of haulage costs in the contract plays a key role in directing and creating incentives for the contractor to locate and use material sources of non-standard quality, the use of which is considered desirable and, ultimately, also of benefit to the roads agency.
- Although the specification should be written to cater for producing an acceptable end product with marginal, variable materials, there may be instances where exceeding the specification minimum may be beneficial to the project. However, a contractor is unlikely to use additional resources or time in processing in order to achieve a better than specified end result unless an appropriate reward scheme is in place.
- In the choice between use of machinery or manual labour, a contractor is likely to select the option that gives the best utilisation of *his own resources* and gives the better cash flow. This may not coincide with the optimal resources for the project from a national socio-economic perspective. Thus, where warranted, it may be necessary to specify certain operational methods in the conditions of the contract.

Construction Stage

The ultimate goal of all parties involed in a construction project is to make the optimal use of the available resources to meet the prescribed standards in the most efficient manner. However, after the project has started, it may not always be possible to make changes in itemisation and payment schedules without incurring a claims situation. Nonetheless, the supervisory staff can facilitate the attainment of optimal solutions in a number of ways which avoid claims. The following are typical examples:

- If available, the use of better quality materials can be promoted by pointing out to the contractor the potential for reducing the time needed for processing of the layer, the often reduced need for the addition of water and a greater likelihood of attaining the specifications more consistently.

- Consistently improving the workmanship/method can justify the increased use of method specifications, reduced frequency of control testing or use of simpler test methods. This will, in turn, benefit the contractor by increasing the speed of construction.

6.2.6 Earthworks Quantities and 'Design and Construct' Methods

The amount of earth-works is decided by:

- **the designer** *where pre-made geometric designs are used*
- **the site staff** *where design by eye methods are used*

The cost of earthworks in LVSR construction comprises a larger proportion of total costs than is the case with major highways where more expensive options for pavement structures and other installations are often used. Thus, a key factor in reducing total road costs is to maximise the use of fill materials in the road alignment and minimise haul distance or, preferably, to avoid it altogether, i.e. cut to fill by machine or to borrow from within the road reserve/side drain. The reduction of fill is a key factor in reducing the cost of earthworks.

"Design and construct" methods can provide benefits in the form of increased speed of construction and, in some cases, reduced earthworks quantities with associated cost savings. However, this approach is only viable where the field staff have the required skills and knowledge and if the appropriate measurement-for-payment procedure is in place.

Box 6.4 - Field staff requirements when using "design and construct" methods

Where "design and construct" methods are used, it is vital that field staff understand the consequences of the selection of alignment. This is important for:

- traffic safety
- internal and external drainage of the pavement
- measures required to deal with poor in-situ soils
- quantity measurement for payment

The horizontal alignment should always be given the highest priority when resources are allocated for alignment selection. This is because of the benefits that accrue from not having to change the road alignment if the road is subsequently upgraded. However, in fixing the alignment, careful attention should be given to a large variety of features within the road corridor, including dwellings, fields, graves, community access, drainage and irrigation channels, catchment areas, proximity of in situ material, avoidance of rock and unsuitable materials, preservation of flora and fauna, etc.

Supply of construction water may involve the construction of temporary pipelines.

6.2.7 Working With Nature

Cost savings can be made where timing of the construction operations can be programmed to suit favourable weather conditions. However, a flexible approach is required for this. In contract work, such an approach may be difficult to achieve owing to contractual difficulties unless the contracts are tailored especially for the purpose. Force account construction offers more scope for flexibility to take advantage of local conditions that often change rapidly and are not easily foreseeable. They allow changes to be made and new procedures to be introduced on site without triggering contractual disputes.

An example of "working with nature" in a hot and dry climate is to minimise the use of water for compaction, thereby reducing associated cost and delays[6]. Such techniques may include:

- Removing overburden from borrow pits before the rainy season in order to allow water to penetrate deep into the gravel seam, thereby increasing the moisture content prior to stockpiling.
- Carrying out compaction of the subgrade during or just after the rainy season (i.e. in conditions nearer to the optimum for compaction).
- Adding and mixing in water at night in order to minimise loss by evaporation.

However, it is important to be aware that it can be more expensive to dry out gravel above the optimum moisture content than to import water for compaction.

LBM

Stabilisation with lime or cement can be successfully applied with basic methods and use of manual labour.

6.2.8 Stabilisation

Not all natural gravels are suitable for use as road pavement materials in LVSRs and some form of improvement may be required to achieve adequate strength and to limit permeability. There are numerous types of stabilisers available for the purpose of achieving these improvements, of which the conventional ones - cement and lime - have had considerable success in the past within the region. Stabilisation with pozzolans can be expected to be similarly effective if applied correctly. Bitumen has become a viable option in recent years as a result of the development of emulsions and foaming technologies for use with natural materials.
In addition to the conventional and well proven stabilisers, the market now offers literally hundreds of brands of alternative chemical stabilisers. However, experience with the use of these stabilisers has generally been mixed and they should be used with extreme caution.

As a general rule, stabilisers of all kinds should only be used after careful consideration has been given to all other options including, in particular, screening of materials to improve their grading or mechanical stabilisation through blending of materials. Unless there is some previous experience of using the products, there is an inherent risk in adding substances to natural materials that may not work as expected and may result in increased construction costs. For example, there is the risk that failure of the stabilisation method could make reworking of the material difficult and costly because previously - stabilised gravel could require the addition of at least 40 per cent fresh gravel for the remedial works.

6.3 Construction Equipment

Traffic loading on newly constructed pavements by construction equipment is a concern on long duration projects where very heavy loading takes place after completion of the surfacing. In such cases, construction traffic should be included as part of the design traffic. Otherwise, work sequence/planning will be needed and measures applied to minimise the effects of construction traffic.

6.3.1 Introduction

The choice of the most appropriate type of equipment for a particular project is normally dependent on the following major factors:

- site condition
- type of operation
- size of the project
- soil conditions and type material used
- the extent to which manual labour is used in the operation

Equipment in current use for construction of LVSRs in the region varies from heavy equipment for major highways to the light plant used for labour-based methods. It will often not be appropriate to use high-capacity, heavy equipment on many LVSR sites because of the smaller quantities of materials and dimensions of the works. Such equipment is certainly not appropriate where labour-based methods are used to any significant extent. Use of manual labour for construction operations requires flexible solutions with many small units of equipment.

6.3.2 Equipment Used with Labour-Based Methods

LBM

Wheel barrows constitute part of the equipment used in LBM.

Fully labour-based methods usually require, in addition to hand tools, the provision of simple equipment such as wheel barrows and perhaps animal drawn carts, often supported by some mechanical transport. In addition, hand-operated compactors may be used for compaction. These require the use of specific methods to be effective, such as construction with a maximum layer thickness of 75 mm, and are unlikely to be effective in operations where pavement materials require compaction on a large scale. Compaction equipment heavier than the light equipment normally used on labour-based unsealed roads may be required for compaction of the pavement layers for sealed roads. Penetration macadam, emulsion-treated base and thin reinforced concrete pavement can all be constructed entirely by labour-based methods, whereas densely graded materials require the use of plant-based methods in order to be effective.

LBM

The concept of using labourers and small tractor-drawn buckets is a good example of labour-based methods.

Labour-Adapted Equipment - Tractor Units

Construction units with agricultural tractors[7] will provide flexibility in the use of the smaller items of equipment that suit operations where manual labour is a major component in carrying out the roadworks. The uses of agricultural tractors in key operations include:

Loading/transport: A small number of tractors can operate, intermittently, many small buckets or trailers, thereby giving labourers sufficient time to load these, whilst maximising the utilisation of the tractors. Buckets and trailers should be of such height that they can easily be loaded by hand. If this is not possible, the bench method can be used to facilitate hand loading.

Spreading/shaping: Graders suitable for towing by agricultural tractors are available in several sizes to undertake spreading and shaping operations. Alternatively, these operations can also be done by hand if some reduction in the regularity of the longitudinal profile can be tolerated.

Watering: Tractors can be used to tow water bowsers fitted with simple spray bars to spread the water evenly on sections prepared for compaction.

Mixing on the road: Agricultural disc harrows towed by large tractors are very effective for mixing, including mixing materials on the road with water and for stabilisation or blending.

Compaction: Towed vibrating, grid or tamping rollers. (For labour-based methods, rollers are often hand controlled).

Surface preparation: Towed mechanical brooms.

For scarification and stockpiling in borrow pits there is little practical use for tractors. Bulldozers and excavators are normally required. Labour can also do this work under favourable site conditions.

Bitumen operations: Towed bitumen sprayers can be used for priming and binder application in conjunction with suitable heating and pumping equipment. For labour-based methods, bitumen emulsions are generally preferred to avoid the need for heating to high temperatures.

Surfacing aggregate: Spreading aggregate by hand from towed trailers - also used for towing backchip units.

A typical tractor unit used in labour-based construction.

Box 6.5 - Advantages of using tractor units

Operationally, tractor-based units have the following advantages that are well suited for use by emerging contractors and for operations in remote areas:

- Plant operation: Fewer mechanical items are in use and units are simple to maintain with ordinary mechanical skills.
- Plant availability: It is often easy to find locally available plant outside the ploughing season, thereby offering flexibility in fleet management.
- Better utilisation of agricultural tractors.
- It is often easier to obtain spare parts for agricultural tractors then for heavy construction machinery.

Typical gravel loading operations.

6.3.3 Heavy Equipment Units

Construction units of various sizes based on conventional equipment, as opposed to tractor based units, have been widespread in the region. The components in typical units of this kind have the following features in the context of constructing LVSRs in remote areas, often by an emerging contracting industry:

Bulldozers for stockpiling: Large bulldozers (example>40 tonnes) are difficult to utilise economically where material sources are small, scattered and of very variable quality within each borrow pit. Smaller models are normally better suited for this operation. Bulldozers require regular preventive maintenance by skilled staff.

Front-end loaders for loading: Front-End Loaders are available in a variety of sizes. They are used mostly for loading gravel but use of this type of equipment is also dependent on the size of trucks available. For LBM, a Tractor Loader Backhoe is also suitable and can load a 6 cubic metre truck in 5 minutes.

Graders are versatile for processing materials on the road.

Scrapers: These are effective where earthworks quantities are large and where material quality is not critical. (The control of material quality is very difficult when using scrapers). The advantage of scrapers is that they can be used for cutting the roadway, excavation of drains, filling, spreading and, to some degree, compaction. However, motor scrapers incur very high investment and operational costs and consequently require high utilisation and mechanical skills for their maintenance. Thus, they are expensive to operate and currently tend to be replaced by a combination of other types of plant.

Motor-graders are versatile and are typically used to level tipped heaps, spread gravel, break down oversize, mix in water, place gravel layers for compaction, cut levels, shape road prism, shape cut-off berms and cut mitres. Most operations carried out by the use of motor graders can be undertaken by labour-based methods. However, on more heavily trafficked roads, it may be preferable to cut the final levels with a motor grader for achieving good riding quality. This can be carried out as a one-off operation whenever a sufficient length (say 20 km) of base has been placed by hand.

Excavators are convenient for various applications, including lifting.

Excavators: Large excavators can carry out the operations of both a bulldozer and a front-end loader for earth-moving in the roadway and in the borrow pits and is an economical option. Selection of material quality is very difficult and such operations can, therefore, be used only where material quality is uniform or can be mixed in situations where quality assurance is not critical (e.g. for bulk earthworks).

Articulated dump trucks: These incur high investment and operational costs with stringent requirements for mechanical skills in their maintenance. They can be efficient in high-capacity operations and provide both an off-road and an on-road driving capability wherever the units can legally use public roads.

Breaking down of any oversize fraction will benefit the grading and quality of the available material.

Tipper trucks: Ordinary tipper trucks are often favoured by emerging contractors because they can be used for other transport purposes and are readily available on the second-hand market, generally with readily available spare parts. The skills required for their mechanical maintenance are moderate.

6.3.4 Compaction Equipment

In addition to conventional rollers for compaction there are other types of equipment that give particular benefits in the construction of earthworks and pavement layers for LVSRs. These includc:

Grid rollers: This is a static roller towed at a relatively high speed (approx.15 km/hour) for breaking down oversize and for compaction. In this manner the material is better utilised and problems arising from oversize particles are avoided. Good results are generally obtained with the use of this plant for the compaction of pavements constructed with natural gravel and of fill layers with marginal quality materials, which can sometimes be difficult to compact to the full layer depth.

The roller allows compaction of the layer to take place in several smaller lifts at the same time as the graders spread the material. This is achieved without forming laminations and shear planes within the layer, because of the pattern of the surface of the roller.

Grid roller.

Close-up of grid.

Pneumatic roller.

Close-up.

3-sided Impact compactor.

Very heavy towed pneumatic rollers: This type of roller can weigh up to 50 tonnes on one axle and has been used successfully for compaction and proof-rolling of the roadbed, especially in thick layers of single-size sand. Its advantage is it provides a uniform and sound foundation for the pavement, achieved by collapsing and densifying any soft areas.

Impact compactors: These are non-circular, relatively high-energy ‘rollers’, typically three-, four - or five - sided. Large-wheeled tractors are used for pulling the compactors at operational speeds of 12 - 15 km/hr producing a series of high amplitude/high impact blows delivered to the soil at a relatively low frequency (90 - 130 blows per minute) with the energy per blow varying between 10 and 25 kilojoules, depending on the mass and amplitude of the compactor.

Owing to their very high *energy density* per blow, their main advantage over conventional compaction plant is their depth-effectiveness, typically of the, order of one metre of fill or in situ layers, thereby producing deep, well-balanced, relatively stiff pavement layers. These rollers are well suited for densifying collapsible soils. They have been successfully used in low-cost road systems and, when appropriately specified, offer a cost-effective option for LVSR construction.

Selection of Compaction Plant

Figure 6.2 provides a broad guide to the selection of compaction equipment. Each roller has been positioned in its economic zone of application. However, it is not uncommon to find them working out of their zones. Moreover, the exact positioning of the zones can vary with differing material conditions.

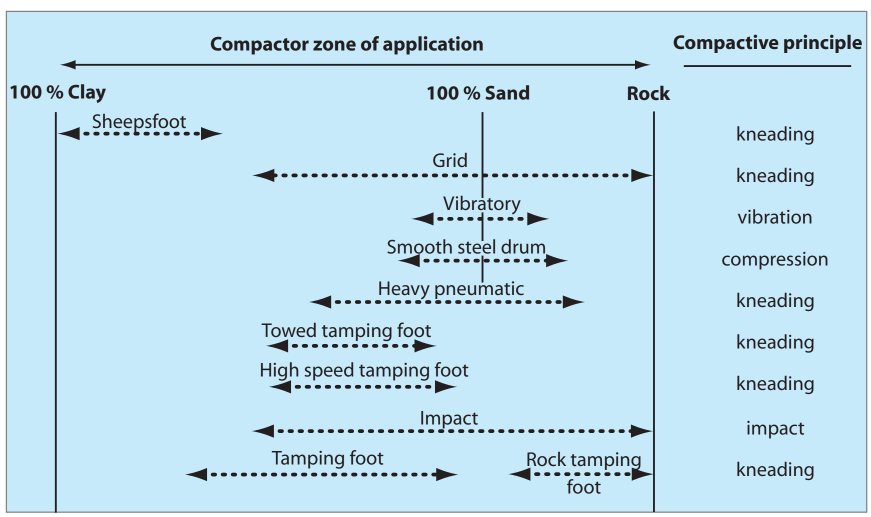


Figure 6.2 - Compaction equipment selection guide[9]

The degree to which soils and natural gravels can be utilized in LVSR construction, instead of more expensive processed materials, will determine the success of the project in terms of economy in both construction and maintenance.

6.3 Utilising Soils and Natural Gravels

6.4.1 General Considerations

Natural Gravel Resources

In areas where natural gravel and soils are available for road building purposes, these materials constitute the most valuable resource in the construction of LVSRs, hence, every effort should be made to use them in a creative manner - a challenge that has met with significant success in the SADC region. However, this has required that particular attention be paid to construction methods.

Large thickness of overburden does sometimes exclude labour-based methods for winning gravel materials. (The example shown in the picture is from construction of LVSRs where the thickness of the overburden is in excess of 2 m).

LBM

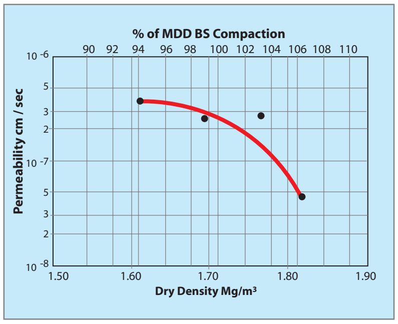
Box 6.6 - Labour-based methods in borrow pit operations

Labour-based methods in borrow pit operations may be utilised for combined stockpiling/loading in pits without overburden and where the ground does not require ripping. Labour-based operations may also be viable in combined operations where heavy plant is used for removal of overburden, while loading is carried out with manual labour. Where bulldozers have removed overburden, it is advantageous to let the same machines scarify the gravel and perhaps undertake stockpiling before manual loading.

Compaction

Compaction is a vital, integral aspect of LVSR construction that results in all-round improvements of soil properties and its performance as a pavement supporting layer. A well compacted subgrade possesses enhanced strength, stiffness and bearing capacity, is more resistant to moisture penetration and less susceptible to differential settlement.

One of the critical aspects of using natural gravels is to maximise their strength and increase their stiffness and bearing capacity through effective compaction. This can be achieved, not necessarily by compacting to a pre-determined relative compaction level as is traditionally done, but by compacting to the highest uniform level of density possible without significant strength degradation of the particles (“compaction to refusal”). In so doing, there is a significant gain in density, strength and stiffness, the benefits of which generally outweigh the costs of the additional passes of the roller.



Permeability-dry density relationship for a lateritic gravel (Kenya).

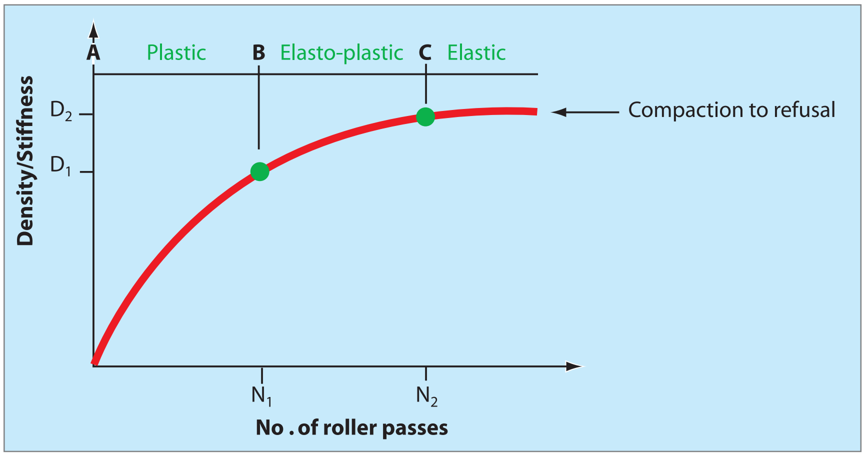


Figure 6.3 - Illustration of concept of “compaction to refusal”

Compaction to refusal ensures that the soil has been compacted to its near elastic state as shown in Figure 6.3 with the significant benefit of reduced permeability and, hence, susceptibility to moisture ingress.

In general, the effectiveness of the compaction process depends on three important, inter-related factors, namely:

- soil moisture content during compaction
- soil type
- type and level of the compactive effort

A maximum allowable moisture content during construction should be specified and proper precautions for surface and sub-surface drainage (where required) should be taken on all road-building projects to ensure optimal performance of the road.

Different types of soils respond to compactive effort in different ways. Thus, it is important to ensure that the compaction plant being used is appropriate for the type of soil being compacted and the purpose intended. For example, sand or sandy soils are most efficiently compacted with high frequency vibrating rollers, whereas cohesive soils are most efficiently compacted by static pressure, high-amplitude compaction plant. In addition, if the requirement is to compact and to produce a good riding quality of base course, this is unlikely to be achieved with a very heavy roller that compacts to a great depth and, in the process, disturbs the surface.

6.4.2 Materials Management[10]

Good management procedures that prevent rejection of material on the road create confidence in the quality assurance system and greatly reduce the risk of shortcuts and poor practice.

Proper management of the material sources is essential to ensure that the best qualities of available material are used in the top layers of the pavement structure. The efforts made to locate the best quality of locally available and often scarce materials for road base are of no avail if this material ends up in earthworks layers. Good management of materials resources is, therefore, a critical operation in LVSR construction.

Box 6.7 - Procedure for materials management

Stockpiling forms an important part of materials management by promoting appropriate selection of materials as well as providing opportunities for blending materials and for testing materials before transportation to the road. The biggest threat to good materials management is when borrow pit operations are not kept sufficiently ahead of the construction.

There is considerable experience to show that the following sequence of procedures will ensure good management of the material resources:

- Initial investigation of material sources by trial holes.
- Stockpiles to be clearly marked.
- Allocation of materials for specific layers on specific sections of the road after stockpiles are completed.
- Laboratory testing should be conducted if possible.
- Loading from stockpiles according to allocation for transportation to site.

It is important to ensure that rejection or acceptance of materials is carried out at the source and not after the material has been transported to the road.

The procedure set out in Box 6.7 requires sufficient plant for opening of borrow pits to avoid construction demands exceeding the materials supply from the borrow pits. In cases where the opening of borrow pits cannot keep ahead of construction, there is a considerable risk that materials selected for basecourse, will end up in the lower layers of the pavement, causing pressure on the supply of material when base course materials are needed at a later time.

6.4.3 Borrow Pits and the Community

Operations in borrow pits will always put a strain on surrounding areas and the environment as a whole. Work in borrow pits has environmental disadvantages, such as temporary noise and dust pollution, and creates traffic safety problems and other hazards to livestock and humans. Some of the effects may remain after construction is completed, such as permanent changes to the topography and disturbance of the soil cover. The Environmental Management Plan, which should be developed in conjunction with the community, will indicate the agreed procedures for the opening and re-instatement of borrow pits.

Wishes of the Community

The wishes of the community will vary according to their needs in the particular area and may include one or more of the following:

- provision of future access to borrow materials for utilisation by the community
- use of the depression for water collection, sometimes requiring fencing or sloping of sides to at least 1:3 for the safety of people as well as to protect livestock from drowning
- levelling of the area in order to prevent collection of water that may lead to mosquito breeding and water-borne diseases
- use of the depression for landfill (rubbish) deposits, always requiring special precautions to prevent pollution
- reinstatement of the area for farming purposes, requiring fertile topsoil replacement, which must be self-draining
- reinstatement and landscaping of the area for building or recreational purposes

It should be noted that the public perception of benefits in leaving borrow pits open is often exaggerated and, as a rule, borrow pits should be reinstated. Before decisions on the future use of a borrow area are finalised, the community should be made aware of the disadvantages of leaving borrow pits open.

Reinstatement of Borrow Pits

The extent of the work required to comply with the wishes of the community will depend entirely on the requirements in each individual case. In the cases where no particular standard for reinstatement has been established, one should routinely carry out reinstatement as described in Box 6.8. The condition of all areas used for access roads should be assessed in the same manner as for the borrow areas.

Backfilling of borrow pits, i.e. replacement of the material from the pit, is only viable where the material for backfilling is either:

- *spoil material, or*
- *originates from a source where excavtions give considerably less disadvantages than in the borrow area. The cost of this method is likely to be very high.*

Reinstatement operations in a borrow pit.

Box 6.8 - General procedure for borrow pit re-instatement.

The following simple procedure will minimise the limitations that the construction activity has placed on future use of the land:

- Shape mounds and steep banks down to a slope (steepest 1:3) that is naturally found in the landscape.
- Spread the topsoil evenly back into the pit in order to promote growth of vegetation.
- Ensure the area is self-draining.

Before reinstating a borrow pit, one should assess the need for materials in future road maintenance and then stockpile appropriate quantities of gravel for this purpose.

6.4.4 Clearing, Grubbing and Removal of Topsoil

It is particularly important to take account of environmental aspects at the early stages of construction so that sensitive operations such as clearing and grubbing are conducted as carefully as possible. It is important that damage to the vegetation cover is minimized, shifting of soil and associated damage due to erosion is avoided and that any mitigation measures set out in the Environmental Impact Assessment are observed, (Section 3.4). All topsoil that is stripped should be stockpiled for use in areas that are being reinstated for farming purposes or to promote vegetation. Any vegetation being removed should be disposed of in a manner that is to the benefit of the community, e.g. for fuel wood.

Burrowing animals such as termites can cause damage to pavement layers unless nests are removed properly and poisoned with an approved pesticide during clearing and grubbing.

Box 6.9 - Clearing and grubbing using manual labour **LBM**

Clearing and grubbing is eminently suitable for labour-based operations where the required speed of construction and availability of labour makes it possible. Labourers may experience problems in achieving the required result as described in specifications due to the need for ripping, depth of grubbing, size of roots, etc. In such cases it is advisable to review specifications in the light of the requirements of a low-volume road and to ascertain whether there is actually a realistic risk of damage to the pavement resulting from reduced standards of grubbing by comparison with current specifications.

6.4.5 Construction of Earthworks

The optimal techniques and methods for undertaking earthworks operations are largely dependent on available equipment in addition to the operational skills and experience of the field staff. Section 6.4 gives an indication of the advantages and disadvantages of the various types of equipment available for earthworks operations.

Research has been carried out to establish whether it is possible to compact fills in dry regions without costly addition of water. Although possible, such practice could result in the compacted layer having a high void content and the risk of settlement at a later time if water enters the fill materials.

When compacting earthworks it may be difficult to adjust in situ moisture content before compaction, especially when using clayey material types where a good distribution of water in the material is difficult to achieve. To mix water into such materials requires much effort and is not very effective. The possibility of adjusting moisture contents of earthworks is particularly difficult in wet climatic regions, whereas in dryer areas it is possible to dry out materials that are too wet. Careful timing of earthworks, where possible, can, to some extent, alleviate the problem.

Box 6.10 - Labour-based methods in earthworks **LBM**

The use of labour-based methods in earthworks is only appropriate where the quantities are moderate or where there is a large source of labour available for the work.

There is evidence to show that the performance of well constructed base courses of natural gravel can be equal to or better than base courses constructed of highly refined, but less well constructed, crushed materials.

6.4.6 Construction of Pavement Layers

Use of Natural Gravel Materials

Optimal use of natural materials is a constant challenge that is faced in the construction of pavement layers for LVSRs. However, depending on local conditions, it may sometimes be necessary to resort to processing of these natural gravels by crushing/ screening, or stabilisation. Natural gravel materials offer levels of performance that are directly related to successful construction methods and workmanship. Aspects of construction that require particular attention are:

In the case of natural gravel with high fines contents, the required density to the full depth of the layer is often far more difficult to achieve then that of well graded granular pavement materials. This often requires special techniques, such as the use of grid rollers, to obtain a good result - see Section 6.3.4.

- Natural gravels with high contents of fines or clay particles gain their strength as a result of suction following drying back, rather than from friction between particles. This means that the in-service moisture regime of the pavement, achieved through appropriate internal drainage measures, is of vital importance for the performance of the layer.
- Correct moisture content (material dependent, however just below optimum moisture content) and achievement of the specified density for the different layers, is essential.
- Depending on the construction plant used, a good surface finish is sometimes difficult to attain. It is essential that the base has a smooth dense surface finish before sealing to ensure that a good bond is obtained between the base course and the bituminous seal and for subsequent good pavement performance.
- Natural materials often include some weak larger particles and, when such materials are compared, these larger particles may break down, hence changing the properties of the material as a whole. An assessment of the consequences of this processing action is therefore required in order to establish whether or not the material meets the specification requirements following construction.

Close up.

The use of mixing equipment, such as ploughs or large disc harrows, greatly reduces the time required for mixing water into the material, by comparison with blade mixing with a grader, particularly where relatively poorly graded gravels with high fines contents are used.

Moisture for Compaction of Pavement Layers

Experience with materials in the region has shown that thorough mixing of water with soil or gravel over the full width and depth of the layer at the optimum moisture content is essential for achieving the required density and an even surface finish. The optimum moisture content for the appropriate level of compaction determined in the laboratory is a good guide to the amount of water required in the field compaction process, although modern compaction plant normally requires a lower moisture content than the optimum indicated from laboratory compaction methods.

Box 6.11 - Effective mixing of water into the material

It is often far more difficult to achieve the required density to the full depth of the layer in natural gravels with a high fines content than in well-graded granular materials. Effective mixing with water is, therefore, of particular importance when these materials are used.

Much as natural gravels may need to be brought near to saturation moisture content for efficient compaction, it is also good practice to allow a significant amount of drying back to occur before sealing takes place. This is particularly beneficial for fine-grained materials that rely on suction and cohesion as their predominant source of shear strength.

Experience has shown that the rapid premature failure of the uppermost layer of the base course can be linked to poor finishing of this layer with subsequent loss of bond to the surfacing.

Finishing of Base Courses

If the operation of mixing, spreading and compaction is not completed before drying out of the surface takes place, then a loose upper layer (biscuit layer) will result. If this happens, the bituminous surfacing will not have a hard surface on which to bond resulting in base course failures resulting from shearing by wheel loads. Such failures may appear to be the result of insufficient material strength, but studies of construction records, and evidence of good performance under similar conditions in base course layers of poorer material qualities, indicate that finishing of the base course layers is vital and decisive for the good performance of LVSRs.

Box 6.12 - Cutting final levels of natural gravel base courses

A critical operation affecting the future performance of LVSR pavements is the cutting of final base levels. Attempts to make minor adjustments to the surface should not be allowed. The cutting of final levels should be confined to the cutting off of high areas and not the filling in of low areas. Thus, it is much better to make corrections to geometric levels at subbase level where surface finish is not critical. Thereafter, construction of the base course can be carried out 'by eye' and with normal control of layer thickness. It is strongly advisable to *cut final levels of natural base courses by eye* rather than by following geometric levels set out in the field.

Figure 6.4 illustrates a recommended procedure for finishing off base courses made of natural gravel. The advantage of this method is the speeding up of the processing of the base course to prevent drying out of the surface whilst ensuring that full attention is given to achieving a good surface finish rather then to dealing with minor irregularities in geometric levels. Trimming of the surface should be confined to the action only of cutting off gravel to side spoil or be off loaded for use in subsequent sections. Spreading loose material over the surface in a thin layer is unacceptable because this is likely to prevent a firm finish of the layer which will inhibit the bond with the bituminous surfacing.

LBM

In most cases, the removal of oversize material is best carried out by the use of manual labour.

LBM

Box 6.13 - Pavement construction with labour-based methods

Labour-based methods for construction of pavement layers have varying potential depending on the type of layer being constructed. Certain types of road pavement and surfacing are more "labour-friendly" than others as far as their construction is concerned.

- Penetration macadam may be constructed entirely by labour-based methods, including production of materials at hard rock sources.
- Granular materials, including natural gravel, may be spread, mixed and levelled by labour. Compaction can be done effectively by labour-based methods as long as the method is appropriate to meet the requirements of a sealed road.
- Improved riding quality is obtained if a motor grader is used to cut the final level.

When trimming off the pattern from grid rollers in the surface of the base, it is important to ensure that any dragging marks from stones is filled in immediately and before smooth rollers are applied.

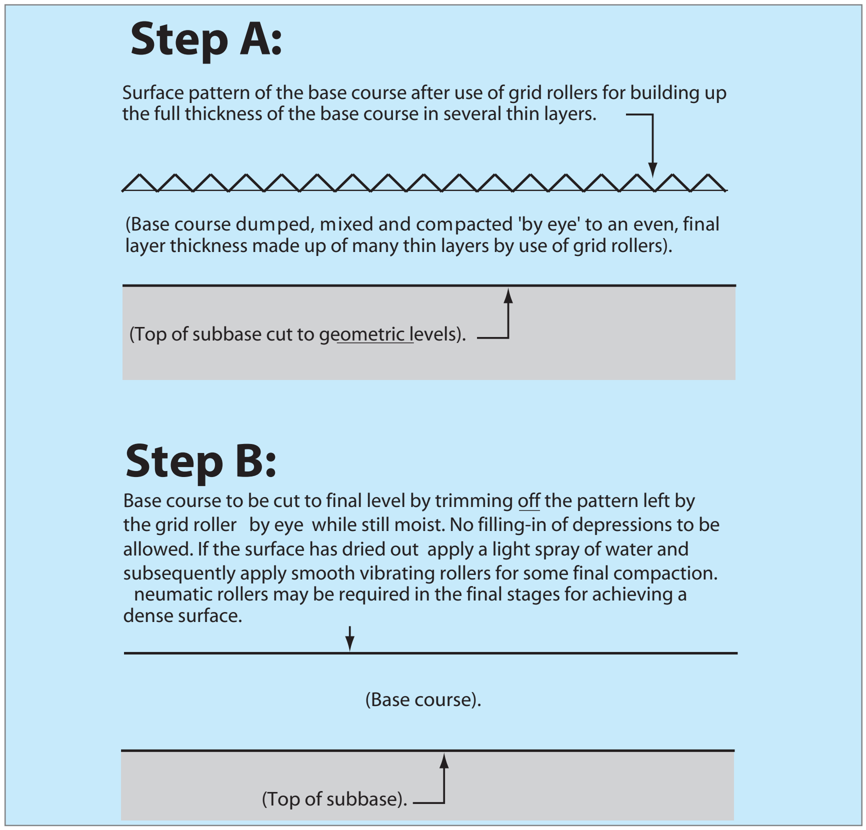


Figure 6.4 - Illustration of procedure to finish off base courses made of natural gravel

Admixture of Kalahari sand to calcrete can potentially improve the material properties by reducing plasticity and improving stability, reducing the damaging effect of soluble salt contents in the calcrete and improving workability to achieve the required density.

6.4.7 Dealing with Variability

Utilisation of Local Material Sources

The mixing of two different materials to achieve a quality that exceeds that of either of the two individual materials is the most common and probably one of the best methods of improving the engineering properties of natural gravels. Mixing fine-graded materials with those that lack fines, such as some volcanic tuffs, can create a material with less potential for breaking down under compaction, with a higher density through improved grading and improved stability and workability.

Mixing of sand in proportions up to a third of the total material quantity has shown benefits without adverse effects. However, the optimal proportion varies depending on material properties. Simple laboratory investigations and field trials (test sections) are required in each individual case.

Box 6.14 - Optimal use of natural gravel

Optimal use of local materials requires innovative engineering solutions to obtain the best performance from available resources. Mechanical blending is often the best option for increasing the quantity of an acceptable material quality or improving the quality of the final material.

When materials are mixed in a borrow pit the proportions will normally be less accurate than when mixed on the road. This method of blending is not recommended.

Separate stockpiling in advance is necessary to control the properties of the individual materials being mixed and the quality of the final material mixture.

Mixing of different material types requires particular attention to be paid to blending the full thickness of the dumped layer of material on to the road, mixing it properly and adding water at the same time.

Mixing by labour-based methods normally gives effective mixing. Where quantities are moderate this method may be a viable alternative to plant mixing.

Unsealed shoulders place particular demands on the type of gravel materials being used as they need to be durable when exposed. This design may therefore complicate operations by requiring separate construction of shoulders and carriageway.

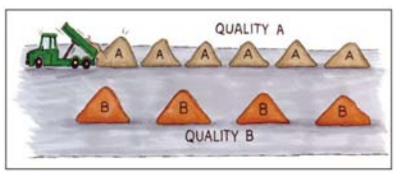
Some mixing during stockpiling is a good option when this process can be carried out by digging through two gravel seams of the materials to be mixed. Bulldozers are not well suited for this purpose nor will heaping the borrow materials in high cones give satisfactory results. Building up stockpiles in layers and subsequently loading from them in a special manner or sequence is feasible but requires very close control of borrow pit operations. Best results are obtained by mixing on the road.

Mixing Technique on the Road

When mixing two types of gravel on the road, motor graders should be used in combination with disc harrows, if available, to achieve a homogeneous mix. The method should be to dump gravel A on the road in the required quantity, then to flatten the heaps and to spread the gravel over half the width of the base course. Then gravel B should be dumped on top of the spread material A and spread over the same half width. Mixing should proceed as normal with the blading of both materials A and B. (See figure 6.5.).

Step A: Separate stockpiling

Step B: Controlled dumping on the road



Step B (Alt.) Controlled dumping on the road

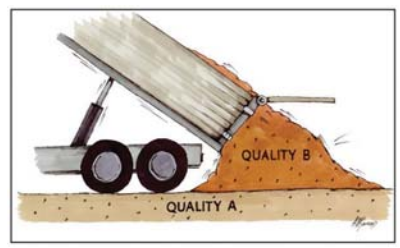


Figure 6.5 - Illustration of two alternative mixing techniques on the road

6.4.8 Shoulder Construction

General

Besides the maintenance and traffic safety benefits gained by sealing of shoulders, there are benefits related to the load bearing strength of the pavement. Sealed shoulders reduce the risk of water penetrating into the pavement layers, resulting in a drier road environment, especially near and under the outer edge of the running surface.

Box 6.15 - Simplified construction with sealed shoulders

The construction of sealed shoulders with the same material as that in the base course is the preferred option. Generally there has to be a considerable difference in material cost for carriageway and shoulders to justify the use of different materials in these two components. It may be justified where highly refined base course materials are used but this is unlikely in LVSRs.

An increasing number of countries in the SADC region are embarking on the sealing of shoulders on roads that were originally constructed with gravel shoulders. This is operationally difficult and there are critical aspects with regard to construction technique that are likely to determine the success of such programmes. The following should be given particular attention:

- Materials in the paved shoulder should be at least as permeable as the materials in the adjacent base. If this cannot achieved, then suitable filters should be incorporated in the shoulder in order to prevent the collection of water in the base.
- A well-compacted joint can only be achieved if the joint between the surfacing and the new shoulder is initially cut straight and clean before shoulder materials are placed.
- The shoulders have to be at least 2.5 m wide to enable a motor grader to mix and place the shoulder gravel as well as to accommodate the width of water trucks and compaction equipment. Excess width can, if required, be cut off on completion of shoulder layer works.
- Shoulders should be finished off and compacted at least 10mm higher than the adjacent base, and subsequently cut to level, as shown in Figure 6.6. Proper compaction and a firm surface for shoulder surfacing is otherwise impossible to achieve.
- Where widening of the road prism is necessary, earthwork fills should be benched and compacted in order to prevent pavement damage resulting from differential settlement.

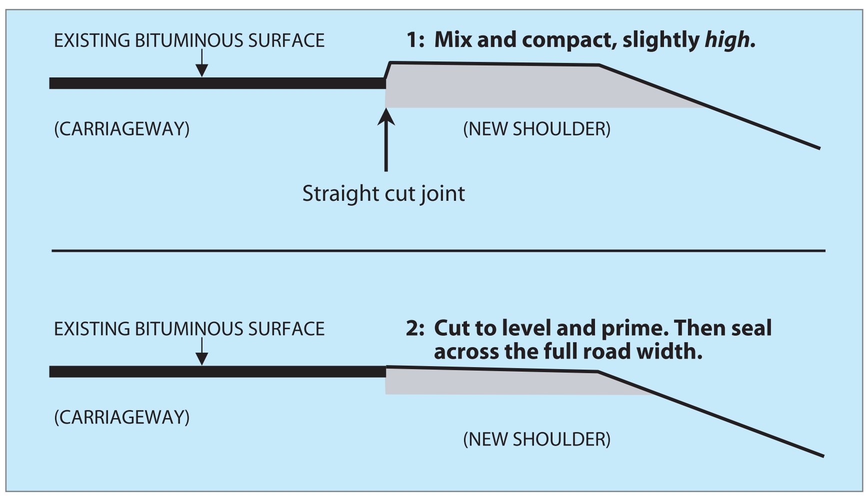


Figure 6.6 - Construction of sealed shoulders to existing bitumenised roads initially having unsealed shoulders

Shoulder Seals

Seals on shoulders should have a higher bitumen content than those on the carriageway, unless the shoulders are expected to be regularly trafficked, e.g. in built-up areas. This can be achieved without higher binder spray rates by using a smaller size aggregate than in the carriageway.

Blinding off shoulder seals with a bituminous ***sand seal*** *is often an appropriate method to:*

- *arrest loss of aggregate*
- *provi de a good surface for pedestrians and bicycles*
- *give a desired visual contrast to the carriageway*

Edge marking of the running surface with a paint line is also desirable if the resources to do this are available.

6.5 Construction of Seals

6.5.1 Selection of Seal Type and Materials

Design of seals and selection of appropriate type of seal is fully covered under Chapter 5 - Pavement Design, Materials and Surfacing.

Decisions on utilisation of aggregate sources for bituminous surfacing often require revision at the construction stage as a result of increased knowledge about available material sources as construction proceeds[10]. This is of particular relevance to LVSRs because:

- A wide range of aggregate types and qualities can be used for the bituminous surfacing.
- Site investigations at the design stage tend to be focussed on identifying bulk materials for the pavement layers. As construction proceeds and materials are excavated for the pavement layers, sources of better quality surfacing materials are sometimes revealed that were not discovered at the design stage.

LBM

Sand seals require lower levels of skill, material quality and equipment than chip seals or Cape seals. If applied over an Otta seal, locally available sand along the roadside may be of adequate quality for the sand seal.

Box 6.16 - Utilisation of local material sources for bituminous seals

Site staff should become familiar with the wide range of seal types and suitable aggregates for LVSRs and with the scope for applying labour-based methods in the production of aggregate and construction of the seal. The inability to fully utilize locally available resources in the construction of low-cost but durable seals results in lost opportunities for achieving construction cost savings.

6.5.2 Resources Required on Site

As indicated in Table 6.1, each of the various types of surfacing has different requirements as regards the necessary resources on site to achieve a satisfactory end result. It is important to observe these requirements when deciding on an appropriate choice of seal for a LVSR.

Table 6.1 - Required input for achievement of a good bituminous seal

	Required input for achievement of a good result *(Low - Moderate - High)*				
	Surface dressing	**Otta seal**	**Sand seal**	**Slurry**	**AC 4)**
Skills	Moderate	Moderate	Low	Moderate 3)	Un-suitable
Equipment, Spreading	Moderate	Moderate	Low	Low	Un-suitable
Equipment, Bitumen Application 1)	Moderate	Moderate	Low	Low	Un-suitable
Materials quality	High	Moderate	Low 2)	Moderate/ High	Un-suitable

1) A bitumen distributor is required for most sprayed seals. Hand sprayers are an alternative, especially when using emulsions, but spray rates need to be controlled. Mixing slurry in concrete mixers is preferred, even when laying by hand. Self-propelled slurry machines increase efficiency but at much higher cost.

2) Coarse sand, sometimes available by screening, can increase the material quality to "moderate" where sand seals are used alone as permanent seals. Where sand seals are used as cover seals, the material quality requirements can be reduced to "low".

3) The selection and handling of bitumen emulsions, including proportioning and adjustment of consistency, increases the need for handling skills. Training is usually required.

4) Although included for comparison with other seal types, surfacing with AC is usually confined to areas with wet climates and/or steep terrain.

LBM

A small, simple crushing/ screening plant can be combined with labour-adapted tractor operations.

Applying aggregate for surface dressing using mechanical chip spreaders.

High contents of dust and fines in the aggregate are more critical for the good performance of a surface dressing than for that of an Otta seal.

Drag brooming is sometimes applied in order to improve distribution of aggregate.

Rolling of sand seal.

6.5.3 Aggregate Production

Table 6.2 outlines the operations required to win and produce aggregate for each type of surfacing that may be used with a LVSR.

Table 6.2 - Production of aggregate for bituminous surfacing

Type of seal	Type of aggregate	Winning and processing of materials
Surface dressing	Crushed stone or rock.	Crushing and screening.
Otta seal	Gravel, natural or crushed.	Stockpiling. Normally screening is also required.
Sand seal (used alone)	River sand (crusher dust may be used, but can be expensive).	Stockpiling (while river is dry). Screening out pebbles.
Sand cover seal (over Otta seals)	Any non-plastic sand.	Stockpiling if sand is not available along the roadside.
Slurry	Crusher dust.	Crushing and screening.

6.5.4 Construction Procedure

All types of sprayed surfacing, such as surface dressings, Otta seals and sand seals, follow a similar construction procedure:

1. Priming of the base (may sometimes be omitted).
2. Base repair (chip and spray by hand using emulsion) to even out the occasional rut caused by a stone under the motor grader blade.
3. Spraying of bituminous binder.
4. Spreading of aggregate.
5. Chip spreading requires uniform aggregate cover. A drag broom can assist this process on large areas.
6. Rolling is preferably carried out with pneumatic rollers but can also be done by trafficking.
7. Repeat steps 2 to 6, if a double layer is applied.
8. An emulsion “fog spray” is sometimes applied to chip seals after they have been laid to enhance adhesion of the chippings.

In slurry seals, crusher dust, bitumen emulsion, water and cement filler are premixed with either a specialised “mix and spread” machine or in a concrete mixer for spreading by hand with squeegees. Mixing by hand is possible but is not recommended.

6.5.5 Labour Friendliness

The various types of bituminous surfacing appropriate for LVSRs offer different degrees of suitability for labour-based application. Table 6.3 provides an assessment of the suitability of each surfacing type for the use of manual labour in the production of aggregate and construction respectively.

Table 6.3 - Labour friendliness of various surfacing types LBM

Activity		'Friendliness' for labour-based methods (*Good – Moderate – Poor*)				
		Surface dressing 1)	**Otta seal 2)**	**Sand seal**	**Slurry 3)**	**AC 4)**
Production of aggregate	Quality	Poor	Good	Good	Good	Poor
	Output	Poor	Good	Good	Poor	Poor
Construction of surfacing	Quality	Moderate	Good	Good	Good	Poor
	Output	Good	Good	Good	Moderate	Poor

1) Hand-crushing of aggregate for surface dressing tends to produce flaky chippings with some rock types.

2) Oversize and fines can be removed by hand screening of natural gravel aggregate for use with Otta seals.

3) Output of aggregate production for slurry (crusher dust) depends entirely on availability on the commercial market.

4) Although included for comparison with other seal types, AC would not normally be used on a LVSR.

LBM

Screening aggregate by labour-based methods (Otta seal is shown, sand seals would be similar).

LBM

Spreading gravel using labour-based methods. (Otta seal), from heaps placed along the road.

Box 6.17 - Labour-based methods in surfacing operations LBM

- The ease of application of labour-based methods for construction of seals varies with seal type. However, in general, all seal types offer good scope for labour-based operations, both as regards production of aggregate as well as construction on site. However, the uniform binder spray rates required for chip seals are more difficult to achieve with labour-based methods.
- Where labour-based methods are desirable, seal types that are most suited for this type of construction should be given the preferential consideration. It may be necessary to provide training to ensure that the final product will be of the desired standard.
- All seals, except the slurry seal, need rolling and therefore require some form of machine-based equipment for this purpose. Where traffic volumes are sufficiently high, it may be possible to rely on traffic for rolling, but at the risk of an inferior result and speed will need to be strictly controlled.

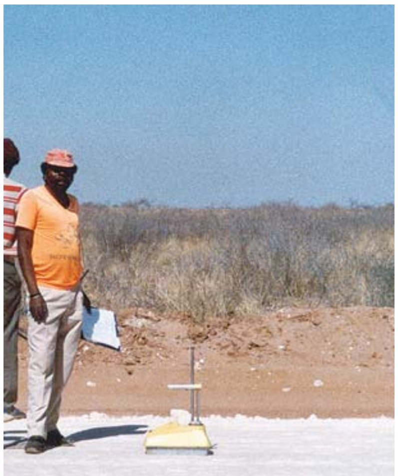
6.6 Quality Assurance and Control

6.6.1 Introduction

Quality control does not in itself create higher quality, but is one of several tools that are used to ensure that a product of the desired quality is produced.

Quality assurance in road construction includes the total system within the construction site that ensures correct quality of the final road and associated structures. Besides conventional site control, quality assurance also includes the measures that contractors themselves apply for this purpose during operations.

Quality control includes laboratory and field testing of materials and construction and forms part of the overall quality assurance system. It is applied in various ways, depending on the type of contract. Conventional contract relations with a supervising body - often a consultant - carrying out control of the works is a common system used in the region. Under these circumstances, end-product quality control is routinely included in elaborate systems and is applied with great effect on projects where roads are constructed. It is commonly considered necessary to establish full laboratory services on site for control of workmanship and material quality. The resources one can afford for such control during the construction of LVSRs are often less, for the following reasons:



Effective quality control for LVSRs does not necessarily require a full-scale programme of laboratory testing.

- The cost of quality control measures that are applied to more highly trafficked roads would represent a much larger proportion of the construction costs of LVSRs.
- Contractors and consultants involved in the construction of LVSRs are often smaller and have less resources available than those routinely constructing larger projects.
- LVSRs are often executed as small projects where the establishment of full site-testing facilities is often not viable. Distances to central laboratory services may also render this option impractical.

This section sets out a conceptual approach to ensure the best possible quality assurance with a reasonable level of control in constructing LVSRs. The inherent compromise in this approach will often require innovative solutions and focus on the overall quality assurance system to achieve optimal results.

6.6.2 Methodology

General

As the **r**esources available for quality control in construction of LVSRs are often limited, it is important to utilise whatever means are available as efficiently as possible and to combine conventional control methods with other quality assurance methods.

Density control is important in 'calibration' of method specifications, but full-scale test programmes are not always viable on LVSRs owing to lack of resources.

Quality Assurance with Reduced Resources

Quality assurance procedures where control systems are applied at reduced levels include the following:

- **stockpiling** as a means of selecting qualities and ensuring known quality of the materials being used
- good **management** procedures to ensure that materials are used to their full potential and to prevent rejection of material after transportation to the road

- systematic use of **method specifications**
- **control by observation** of construction procedures by an experienced practitioner
- **proof rolling** (e.g. with loaded trucks) to test the stability of layers before proceeding with construction
- use of methods for **direct strength measurements** by correlation with known parameters (e.g. probing methods such as DCP and others)[11]
- laboratory testing for **'calibration'** of method specifications
- laboratory testing of typical material sources for **'calibration'** of visual observations

Having spray cans with bitumen emulsion available at all times during surfacing operations for repairing minor faults is part of good quality assurance.

Priority in Quality Control

Box 6.18 - Optimum priority for quality control

The resources put into quality assurance should be applied where there is a maximum benefit from the efforts, i.e. where the benefits, in terms of structural life or surface life, are greatest in relation to efforts made in the control.

Direct strength measurement can assist but cannot replace materials management and observation of the work procedures as the most powerful means of quality assurance.

LVSRs typically utilise natural gravel in the base course, followed by a thin bituminous seal. This pavement structure is sensitive to any irregularities in the seal, in the interface between seal and base course and in the base course itself. Conceptually, the priority when allocating resources to quality assurance should therefore be as shown in Table 6.4. The table sets out the priority on the basis of what is possible from a technical point of view in relation to the input of resources for control. It does not take account of contractual and institutional issues. These aspects will vary considerably and require varying measures for optimal quality assurance.

Visual control of the bitumen distributor and continuous inspection of the work on site are important parts of the quality control procedures and can reduce flaws in thin seal that could lead to premature failure of the surfacing.

Continuous visual control by skilled staff through the entire operation when processing the base course for LVSRs is essential. Inadequate compaction of natural gravel is often caused by poor mixing, insufficient moisture content or poor final spreading and compaction of the layer.

Table 6.4 - Priority in quality control

Priority	Layer	Comments
1	Bituminous surfacing	• Choice of equipment, choice of material type, visual assessment and measurement of application rates is of greatest importance. • Only basic laboratory equipment is essential for effective control during operation.
2	Surface finish of the base course	• Biscuit layers are the most common reason for an unacceptable product. A geological hammer/pick can be used to identify such flaws. • Visual assessment, plus choice of equipment and working method is of greatest importance. • Laboratory equipment is not essential for effective control during operation.
3	Material quality of the base course	• Laboratory tests in advance and after construction, combined with indicative tests or observations during construction, are essential.
4	Compaction control of the base course	• Method specifications, appropriate choice of method and equipment, visual assessment and proof rolling, in combination with regular testing for 'calibration'. • The extent of testing required for 'calibration' purposes should be adapted to site conditions and available resources.
5	Subbase and earthworks	• Visual assessment and laboratory tests ahead of construction give improved confidence in material quality. • Method specifications, visual control, proof rolling and appropriate choice of method and equipment are sufficient for site control of workmanship.

6.7 Drainage

6.7.1 Introduction

Drainage is probably the most dominant factor affecting the performance of a LVSR. When such roads fail it is often because of inadequacies in drainage resulting in the ingress of water into the road structure, structural damage and costly repairs. In addition, surface water can form a road safety hazard by causing aquaplaning of vehicles.

Unfortunately, many LVSRs have evolved with inadequate initial engineering and drainage design. Even with properly engineered LVSRs, on-site inspection is often necessary to correct any unforeseen conditions during construction. Such an approach is more cost-effective than maintaining or correcting deficiencies after the road has been in service for several years.

Two inter-related aspects of drainage require careful consideration during construction, namely:

- *Internal drainage* of the pavement which seeks to avoid the entrapment of water by allowing it to permeate through and drain out of the pavement structure.
- *External drainage* which seeks to divert water away from, and prevent its ingress into, the pavement structure through measures such as the construction of sealed shoulders, side drains, etc.

6.7.2 Internal Drainage

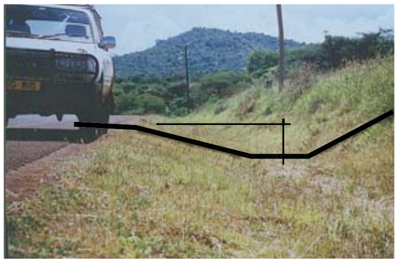
General

It is important to create an awareness amongst the public so that actions that lead to impaired drainage of the pavement can be prevented.

Internal drainage involves measures to minimise moisture contents in the embankment and pavement layers and importantly to prevent unwanted movement of water within the structure. Internal drainage is vital for the satisfactory performance of earthworks and pavement layers made of natural soils and gravel, especially those that utilise fine grained and plastic materials such as those commonly used for LVSRs[12]. (Refer to Chapter 5 for more details).

Permeability of pavement layers

Wherever possible, each layer in pavement and earthworks should be more permeable than the overlying layer in order to prevent any water entering the structure from being trapped. It is often not possible to meet this requirement consistently and the provision of cross-fall in all earthworks and layer works for water to escape from the pavement structure can alleviate the problem (see also Section 5.4.3 and Box 5.7). Under severe conditions, especially where there is risk of water seepging into the pavement structure, consideration should be given to installing subsurface drainage systems or, better still, to increase the height of the road in such areas.



Research in the region has shown that a minimum crown height is a critical parameter that correlates well with the actual service life of pavements made of fine grained and/or slightly plastic materials. A minimum crown height of 0.75 m is recommended. See Chapter 5 - Pavement Design, Materials and Surfacing, Section 5.3.4.

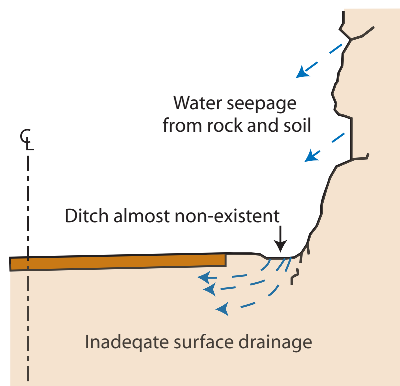
Crown Height

Crown height is the vertical distance from the bottom of the side drain to the finished road level at centre line and needs to be sufficiently great to allow proper internal drainage of the pavement layers. Economical ways to achieve sufficient crown height include the use of material from the side drain and road reserve a common procedure where scrapers/motor graders are used for construction. Maintaining sufficient crown height through cuttings is of particular importance, owing to the unfavourable drainage conditions in such areas. However, this may result in a considerable increase in the quantity of earthworks cut. Alternatives, such as subsurface filter drains, should be considered as a last resort because of cost and maintenance implications. The traffic safety aspects of large crown heights should be taken into account by moving the side drain further away from the shoulder break point.

In areas where in situ soils are considered to be self-draining, such as in sandy areas and desert-type areas, priority should be given to providing good side support within a low embankment profile and shallow side slopes (typically 1:6 or 1:8) rather than a large crown height and relatively steep side slopes.

Seepage and subsurface drains

Unfortunately, inadequate surface and subsurface drainage are typical deficiencies associated with cut-and-fill pavement sections for LVSRs, as shown in Figure 6.7. Such deficiencies can affect the pavement by erosion, decreasing soil support or initiating creep or failure of the downhill fill or slope. They should be addressed during construction rather than waiting until failures occur because it is much more expensive to undertake remedial works.



Blocked side drains may lead to surfacing failures.

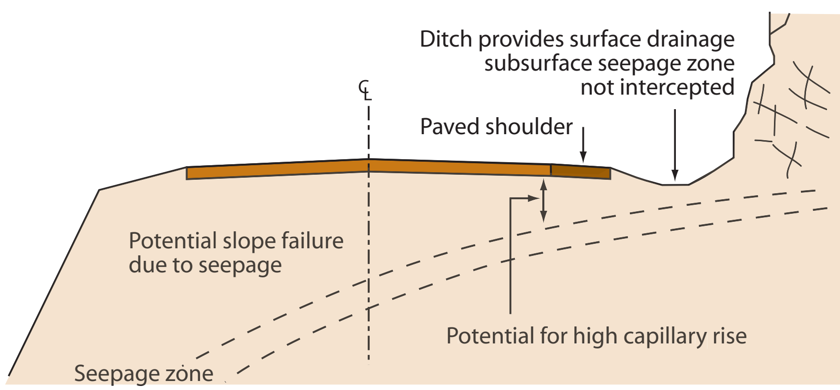


Figure 6.7 - Typical drainage deficiencies associated with cut-and-fill pavement sections[13]

In the design of the vertical alignment of LVSRs, it is advisable to try to avoid cutting into the ground to reduce the risk of encountering subsurface water. Thus, the "depressed pavement construction" shown in Figure 6.8 should be avoided except where soil moisture conditions are suitable or the drainage systems effectively eliminate water-related problems.

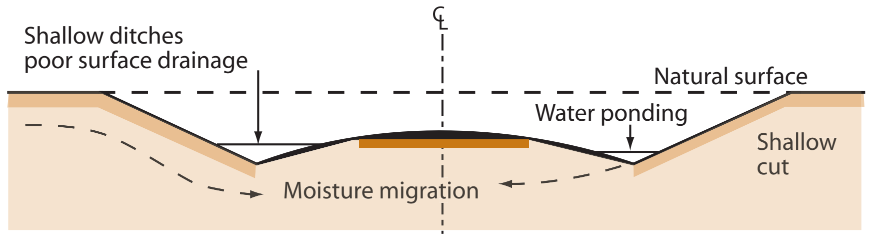


Figure 6.8 - Potential drainage problems associated with depressed pavement construction

Localised seepage can be corrected in various ways but seepage along pervious layers combined with changes in road elevation (grades) may require sub-surface drains as well as ditches, as shown in Figure 6.9.

Subsurface drains can be made of geo-textiles wrapped around aggregate, with or without pipes installed, but various specialised systems are also marketed. Such drains have commonly been made out of aggregate surrounded by filter sand instead of geotextiles, depending on the grading of the in-situ soils.

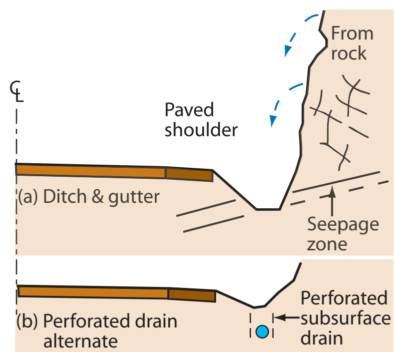
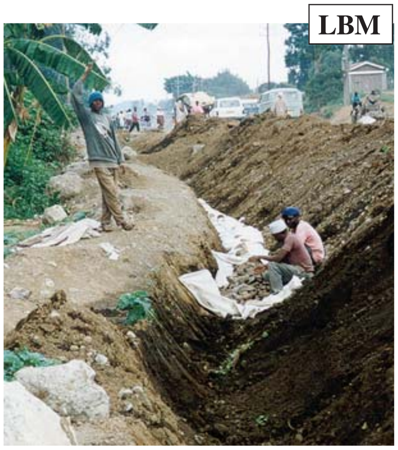


Figure 6.9 - Beneficial interception of surface runoff and sub-surface seepage[13].

LBM



Construction of filter drains is well suited for labour-based methods. Geotextiles used for filter drains should be of a type that does not get blocked by fines from surrounding soils.

As subsurface drainage systems usually incur relatively high installation costs and there is the risk of blocking of buried systems, alternative options are preferred.

Shoulders

Construction of shoulders needs to be undertaken carefully if typical drainage problems are to be avoided. Preferably, the granular base should extend to the embankment slope with sufficient height above the ditch to prevent water intrusion. Trench, canal or "bathtub" construction, in which the pavement layers are confined between continuous impervious shoulders, should be avoided as this has the undesirable feature of trapping water at the pavement/shoulder interface and inhibiting flow into the drainage ditch.

Shoulder materials should be selected which have a permeability similar to that of the base course, so that water does not get trapped within the pavement. However, the material properties for unsealed shoulders may well be different from those required for the base for reasons of durability. Unsealed shoulders are similar to a gravel wearing course and require material with some plasticity, which is a property that might be considered less desirable for road base material.

A common problem is water infiltration into the base and subbase, which occurs for a number of reasons as, illustrated in Figure 6.10. These include:

- rutting adacent to the sealed surface
- build up of deposits of grass and debris
- poor joint between base and shoulder (more common when a paved shoulder has been added after initial construction)

Water infiltration in shoulder and rut leading to edge failures.

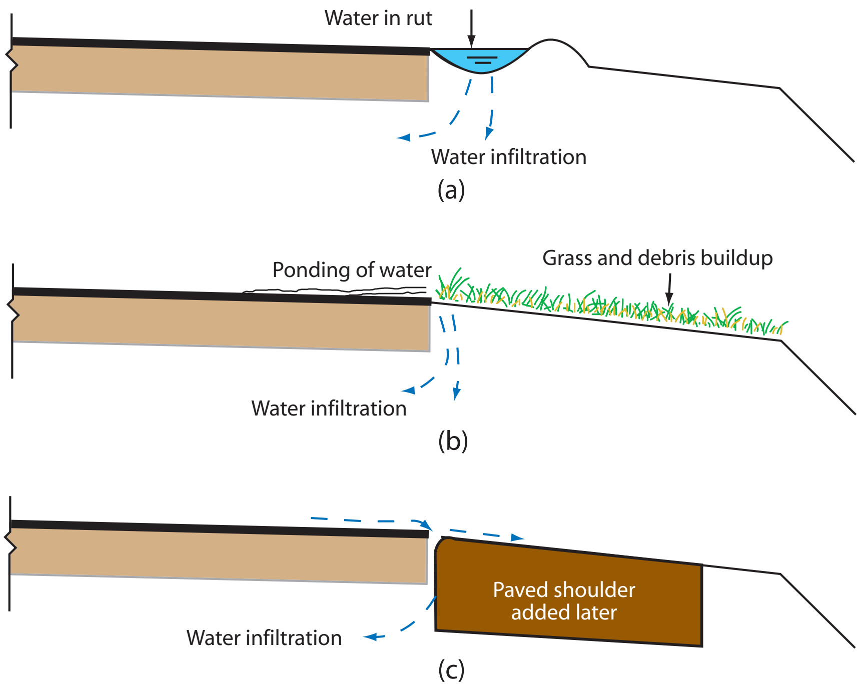


Figure 6.10 - Typical drainage deficiencies associated with pavement shoulder construction[13]

Ideally, as illustrated in Figure 6.11, the base and subbase layers should be extended outwards to form the shoulders, which should preferably be sealed.

Use of different materials in the shoulder and the carriageway is often uneconomical because of disruption in the construction procedures. Use of the same material in the carriageway and the shoulder eliminates the risk of trapping water.

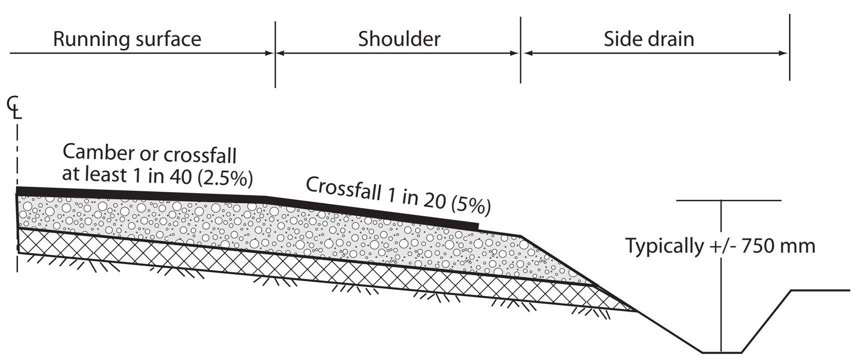


Figure 6.11 - Ideal shoulder construction/drainage arrangements

Caution is required in undertaking drainage work as interference with the natural drainage pattern can lead to major environmental damage in sensitive areas.

6.7.3 External Drainage

Introduction

External drainage involves methods of crossing of watercourses, measures to divert water away from the road and prevention of damage caused by erosion. In the construction of LVSRs there is often wide scope for the use of various measures to improve external drainage, such as low-level structures, drifts etc. where 100% passability to traffic throughout the year may not be required.

It is not within the scope of this Section to provide a *detailed* description of all the various measures that make up a good drainage system. Conditions on site will vary tremendously in respect of in-situ soils, topography, vegetation, climate, human settlement patterns, environmental concerns, etc. The skills of site personnel and knowledge about local conditions are critical for successful installation of mitre drains, catch-water drains, side drains, berms, channels, cut-off drains and crossings along the road [14].

6.7.4 Hydrology and Hydraulic Calculations

Introduction

The use of sophisticated methods to estimate run-off and for the calculation of the size of waterway structures is not always appropriate for LVSR because either the data and/or the resources required are not available. Thus, alternative methods, which also rely on visual observations and historical evidence from consultations with the local populations are often more appropriate. Furthermore, financial constraints also mean that a compromise is often required between structures that provide all-weather access and those that can be constructed with the available resources.

Method

The capacity of drainage structures should ideally be calculated on the basis of local experience gathered over a long period of time and should be updated to cater for any recent changes in rainfall pattern and climate. However, such information is often not readily available in many countries, prompting a need to develop standards for drainage design and calculations. In all cases it is advisable to combine calculations with observations on site, in addition to information from reliable local sources.

With the ever-increasing cost of maintenance, it is desirable to increase the size of drainage structures to a minimum of a 600 mm opening so that they can be easily maintained.

Overtopping on LVSRs, although undesirable, has less impact on the economy than if it occurs on HVRs.

Return Period

The return period for a given flow of water is related to the estimated statistical risk of overtopping of drainage structures. It is part of the hydraulic calculations required for each type of structure for each project on the basis of policy and anticipated consequences to the road or the public. The return period is therefore a critical parameter in the design of LVSRs because it controls the level of risk in relation to cost of construction and the type of structure that is appropriate. As a broad guide, the following return periods can be considered for LVSRs:

- Bridges: 10 - 50 years.
- Culverts: 5 - 10 years.
- Drifts or well-protected culverts: 0 - 5 years.

6.7.5 Drainage Structures

LBM

Inadequate culvert capacity, particularly in combination with high embankments can result in severe damage and expensive remedial works.

Low-level drift.

Vented drift.

Banks of pipe profiles culverts are prone to blockage by trees even when large sizes are used.

Introduction

This chapter gives some examples of the range of solutions available to designers and constructors of LVSRs. The techniques shown are the results of innovative methods tried out and applied in many countries in the region over a number of years. A basic requirement in the construction of structures for crossing water courses is to assess the need for protection of the structure against erosion during the construction period as well as assessing the risk that structures that are not designed to withstand flooding will actually experience overtopping, so that additional protection measures can be taken. Construction of low, "sacrificial" points for overtopping should be considered where available resources do not allow for the provision of structures with adequate capacity [15].

Low-level structures

A low-level structure is designed to accept overtopping without damage, and is ideally suited for LVSRs in locations where less than full all-weather passability is acceptable to the community. The two basic types listed below have been used with success in the region. Various alternative names are sometimes used to describe these structures.

- **Drifts** are designed to provide a firm driving surface in the riverbed, where traffic can pass when water levels are moderate.
- **Vented drift** sometimes named fords, causeways or Irish bridges, larger structures are called low level bridges) allow water to pass through openings, but can withstand overtopping without damage. Openings in vented drifts should, like culverts, be made large enough, preferably not less than 0.9 m so that cleaning during future maintenance is made easier and the risk of blockage is minimised.

A common feature of all low level structures is that they require proper foundations and anchoring, as well as scour protection to the road prism.

Culverts

Types: Culverts are constructed on LVSRs using a variety of methods and materials. Examples include corrugated plastic pipes, steel pipes or arches, pre-cast or fresh concrete pipes, boxes, arches or half arches ("shelverts"), reinforced concrete slabs resting on blockwork in a box culvert profile and wooden culverts in a box or circular profile.

As indicated in Box 6.19, there are many innovative ways of producing inexpensive culverts.

LBM

Inflatable rubber balloons have been used successfully as formwork for construction of concrete pipe culverts on site. Concrete is poured directly against the side of the trench, which is protected with plastic sheets.

Upstream protection against blockage by trees can be successfully constructed from old railway steel sleepers well-anchored into the riverbed.

LBM

Concrete culverts are only practical for use in labour-based methods if each section is not too heavy for handling by labour or by mechanical equipment available on site.

LBM

Box 6.19 - Innovative construction of culverts

Innovative methods are in use in the region for simple and efficient construction of culverts that are particularly well suited for application in LVSRs, especially where labour-based methods are used. Examples of such techniques include:

- use of locally produced treated planks (pine) for yard production of pipe culverts, strapped with steel bands (Tanzania)
- use of inflatable rubber balloons as formwork for site casting of concrete pipe culverts in a large variety of dimensions (Tanzania) up to several metres in diameter
- use of drums as formwork for standardised yard production of concrete modules for pipe culverts (Zimbabwe)
- use of drums as formwork (left behind) for site casting of concrete pipe culverts (Tanzania)
- use of timber for site construction of square profile culverts
- use of blockwork for site construction of square profile culverts (Botswana)
- shelverts are pre-casts concrete half-arches that require less skill for construction than culverts
- masonry vertical brick walls with concrete slabs cast on site

Location: Wherever possible, culverts should be located in the original stream bed with the invert following the grade of the natural channel. Stream bed realignment may be undertaken in exceptional cases.

Skew culverts: Water courses intercepting the road at an angle of skew of less than 20 degrees can generally be accommodated by a culvert placed at right angles to the road centre line. In such cases, the culvert inlet should be positioned at the point where the channel meets the road, and any modification to the channel made downstream of the outlet. Water crossings with a skew angle greater than 20 degrees should be provided with a skew culvert.

Inlets: To avoid silting, culvert inverts should be placed at a grade of not less than 1.25 per cent for pipes, and 0.5 per cent for box culverts. Invert gradients should be increased by one per cent in the case of culverts provided with drop inlets.

Outlets: The invert level at the outlet of a culvert should coincide with ground level. Where culverts are unavoidably constructed on a steep slope, the energy generated must be dissipated to avoid serious erosion at the discharge end of the culvert. A stilling box and widening at the outlet are effective methods of reducing the velocity of the water.

Foundation: Ideally, culverts should be located on sound foundations such as rock. Soft, saturated and expansive clayey soils may cause settlements or seasonal movements of the culvert. Removal of poor soils or stabilisation of the foundation should be considered.

Use of Labour-Based Methods

Labour-based methods are very well suited for the construction of drainage structures, excavation of drainage channels, construction of soil berms, stone pitching, scour protection, etc. Pre-cast concrete culverts are not well suited for LBM if the weight of each element is too great for manual handling.

Blockwork has been used successfully for simplified construction of headwalls on small culverts and for the support of concrete slabs to make a box culvert.

Erosion in outlet channels can cause considerable environmental damage in sensitive areas.

Concrete scour checks in side drain.

When there is a risk of erosion at outlets, suitable aprons and other protective measures are required.

6.7.6 Erosion

Introduction

Any disruption to the natural flow of water carries a risk of erosion that may lead to environmental degradation, silting, damage to roads, damage to buildings and services, destruction of farming land and loss of fertile soil. Thus, there is a responsibility to ensure that the construction of the drainage system for a LVSR receives the same attention to good practice as the construction of other roads. Indeed, avoidance of erosion can be more critical in the case of LVSRs because of the greater challenges faced in maintaining the drainage system in remote areas where these roads are often located.

Scour Checks

There are many examples in the region of inexpensive and effective methods that are used to protect drainage channels and side drains by the use of scour checks that are easily constructed by labour-based methods. The scour checks can be made of wooden sticks, rocks, concrete or other materials depending on the most economical source of materials. The frequency of scour checks needs to be properly adjusted according to slope gradient in order to prevent erosion between the checks causing damage to the system. The following can be used as a guide:

Gradient of the ditch	Scour check spacing (m)
4% or less	(not required)
5%	20 m
8%	10 m
10%	5 m

Erosion of Culverts

Short culverts requiring high headwalls and wingwalls are prone to erosion around both inlets and outlets, especially along the wingwalls. Constructing culverts that are sufficiently long to reach the toe of the embankment will minimise necessary protection measures, future maintenance and the risk of damage to the embankment around the openings. It is necessary to carefully assess the additional cost of lengthening culverts against these benefits, especially in the case of LVSRs that are often located in remote areas where regular maintenance is a challenge.

Slope Protection

If required, placing of topsoil and planting of vegetation on the slopes of embankments should take place in order to minimise erosion before indigenous vegetations can establish roots.

Box 6.20 - Planting of vegetation for protection of slopes against erosion

Where grass or other vegetation is planted for protection of slopes, it is absolutely vital that professional advice to be obtained from a botanist. Failure to do this could lead to intrusion of non-indigenous species that could threaten the environment or cause damage to local farming.

6.8 Summary

The key points raised in this chapter are:

1. The characteristics of LVSRs are such that the methods employed for their construction may be different from those for more highly trafficked roads. In some circumstances labour-based methods can be effectively employed for many, if not all, of the construction activities.

2. Construction of LVSRs are often carried out in remote rural areas. These circumstances can give rise to special problems relating to health, safety and the environment and appropriate measures need to be taken to ameliorate any detrimental effects of the road construction processes on local populations and the environment.

3. A higher degree of awareness of the properties and use of materials is required in the construction of LVSRs so the use of the (often) scarce resources of good quality road-building material can be well managed.

4. The nature of LVSRs construction provides a range of both technology choice and equipment use. The selection of equipment must be matched to the chosen technology in order that the the highest quality of construction is attained with the resources available.

5. Compaction of natural gravels is an essential component for the good performance of LVSRs. Where the materials are suitable, compaction to refusal during construction adds relatively little to construction costs but is likely to produce significant benefits from improved road performance. Conversely, poor compaction is likely to lead to lower density, moisture ingress, deformation and increased maintenance.

6. Good quality control during construction is important in the construction of all roads but is particularly important on LVSRs, where greater use is made of locally available resources. It is important that these roads provide a good quality riding surface and pavement performance so that unexpected maintenance inputs do not occur.

7. Many of the natural gravels used in the construction of LVSRs provide high strengths when dry but are also moisture sensitive. Keeping the pavement dry through good drainage is, therefore, a critical factor in the performance of LVSRs and it is important that measures that reduce moisture ingress are applied at the construction stage rather than later, when they are generally much more expensive to carry out.

8. Perceived risks associated with the use of unconventional approaches, technology and materials can be sensibly managed through relatively low-cost measures that ensure good performance.

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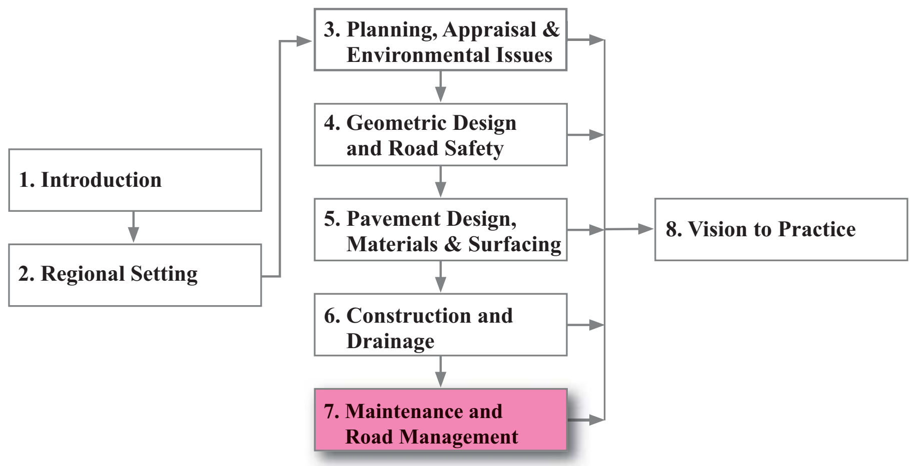
Chapter 7



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Maintenance and Road Management

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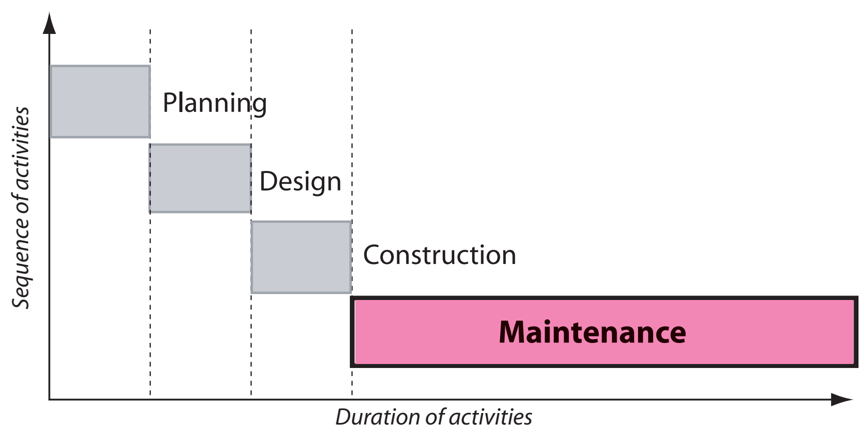
7.1 Introduction

7.1.1 Maintenance



Definition of road maintenance

"To conserve as nearly as possible, the original designed condition of paved and unpaved roadways, and of traffic signs, signals and markings, in a manner most likely to minimize the total cost to society of vehicle operation and accident cost, plus the cost of providing the maintenance itself, under the constraints of severe resource limitations, in respect of skilled manpower, equipment and money, both local and foreign." (PIARC).

Road maintenance is an integral component of the LVSR provision process, the type and cost of which are influenced significantly by decisions made during the preceding planning, design and construction phases. Proper maintenance contributes to the preservation of the road asset and to prolonging the road's life to its intended service duration. Without adequate maintenance, roads deteriorate rapidly, become dangerous and costly to use and, ultimately, the costs to the economy are substantial.

Whereas design and construction of LVSRs are dominated by engineering issues, maintenance is essentially a multi-dimensional issue in which the management and technical aspects are influenced by political, social and institutional issues. For example, the use of maintenance works as a poverty alleviation tool through appropriate community involvement is assuming increasing importance.

Maintenance currently constitutes one of the major preoccupations of roads agencies in the SADC region. In the early stages of road development, most of the road expenditure was spent on construction. However, as these networks have become more developed, the expenditure required for adequate maintenance and rehabilitation has increased relative to that required for new construction.

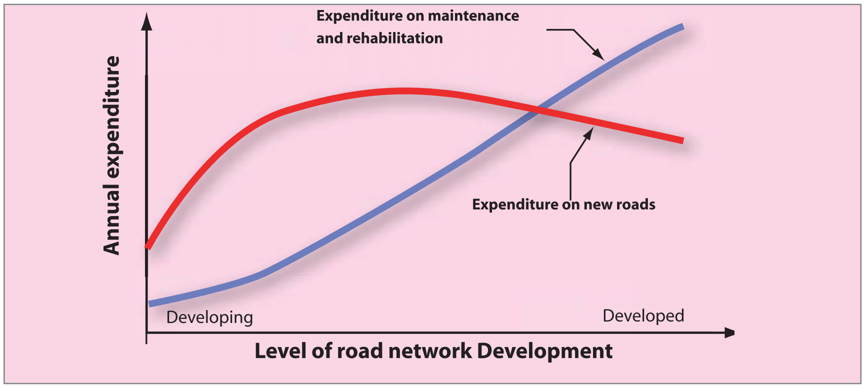


Figure 7.1 - Pattern of road expenditure in the SADC region

Example of a badly deteriorated road that has received little, if any, maintenance since it was first constructed? Result? Very high vehicle operating costs and loss of most of the original investment.

Unfortunately, for a variety of reasons, including lack of adequate funding, provision of satisfactory road maintenance still remains an elusive goal for a number of SADC countries. As a result, these countries, and the region as a whole, have paid a high price in terms of deteriorating road networks, very high transport costs and the reluctance of donors to assist with the funding of new or rehabilitation projects. Fortunately, however, roads agencies are beginning to tackle the maintenance challenges in a more holistic manner to improve efficiency and effectiveness and to achieve sustainability.

7.1.2 Road Management

The SADC road system represents a major investment and is one of the region's largest public sector assets, with a replacement cost of more than $50 billion (2000). Indeed, the asset value of the road system often exceeds the combined value of all the other surface transport systems. Therefore, it is extremely important that this asset be preserved through effective and efficient management. In the absence of this, the investment can be eroded quite quickly because roads that are not maintained deteriorate very rapidly.

Even for relatively low-trafficked road networks, reliable information has become essential for effective management. This has led to the development of management tools, including various types of road management systems, that assist roads agencies in allocating resources in a manner that achieves the best value for money. However, to be sustainable, such systems should be carefully chosen to match the available resources - both technical and financial - of the roads agency. Unfortunately, there are a number of examples of systems which have failed to work satisfactorily.

7.1.3 Purpose and Scope of Chapter

The main purpose of this chapter is to provide guidance on how to improve the maintenance and management of LVSRs through the adoption of appropriate institutional arrangements, management strategies and technical standards. Guidance is also given on criteria for establishing road management systems to assist roads agencies in the overall management of their road networks. Aspects of maintenance operations are not covered in detail because sufficient reference texts on this topic already exist.

7.2 Maintenance Issues

7.2.1 Maintenance Setting

Why Maintenance?

The case for maintenance is compelling. Having spent time, effort and money in planning, designing and constructing a road, it is vital to ensure that the asset is preserved by timely and effective maintenance. Such maintenance has three principal purposes:

- it prolongs the life of the road and postpones the day when renewal will be required
- it reduces the cost of operating vehicles on the roads
- it helps to keep roads open and ensures greater regularity, punctuality and safety of road transport services

The first purpose corresponds most directly to the interest of the roads agency, the second to that of operators of vehicles, and the third, more generally, to that of the inhabitants of the area traversed by the road.

Routine maintenance: *Fixed cost activities that are carried out irrespective of the engineering characteristics of the road or the density of traffic (e.g. grass cutting) and cleaning of drains.*

Recurrent maintenance: *Activities required throughout the year but whose frequencies vary with traffic, topography and climate (e.g. road marking).*

Periodic maintenance: *Those recurrent activities that are required at intervals of several years (e.g. resealing).*

Lengthman: *A man engaged on a contract basis responsible for routine maintenance on a fixed length of road adjacent to his own home. He is paid a fixed sum per day or month to keep drainage ditches clear, fill in potholes, cut grass, repair minor erosion to shoulders, etc.*

Typical Maintenance Activities

Maintenance activities are either *cyclic* or *reactive* and can be of a *routine* or *periodic* nature. Cyclic activities are those that are carried out at regular intervals. Reactive activities are those that are carried out in response to an occurrence e.g. erosion, drainage repairs or a condition defect exceeding values dictated by maintenance standards, e.g. rutting greater than a given value.

Table 7.1 - Maintenance activities

Works Category	Maintenance Activity	Type	
		Cyclic	Reactive
Routine Maintenance	*General:*		
	Grass cutting	x	
	Removal of obstacles		x
	Culvert clearing/repair		x
	Bridge clearing/repair	x	
	Drain clearing	x	
	Erosion control/repair		x
	Carriageway markings		x
	Repairing road signs		x
	Pavement:		
	Pothole repairs		x
	Surface patching (local sealing)		x
	Crack sealing		x
	Edge repairs		x
Periodic Maintenance	Rejuvenation seal		x
	Resealing		x
	Shoulder regravelling/reshaping		x

Grass cutting - a typical, labour-based, routine maintenance activity.

Many of the activities in Table 7.1 can be carried out cost-effectively using labour-based methods. If some of the routine maintenance work is contracted on a "lengthman contract" basis, for example, there would be little or no requirement for maintenance labour camps for transport to and from the work site, thereby saving money. Some periodic maintenance work may still require specialised equipment, e.g. bitumen sealing operations, but labour-based methods can be used for many activities.

Lack of attention to simple maintenance tasks can impose a multitude of problems for road users, society and the national economy, as illustrated in Table 7.2.

Table 7.2 - Maintenance problems, effects and solutions

Road Safety		
Issue/Problem	**Effect**	**Solution**
Vegetation growth	Impairs driver visibility	Ensure safety standards are established and maintained. Carry out routine inspections to identify deterioration likely to lead to a reduction in road safety. Record and analyse accident data to provide clues to maintenance deficiencies .
Potholes	Danger to motorists	
Flooding (blocked culverts)	Reduces pavement strength	
Dirty, damaged or missing traffic signs	Increases likelihood of traffic accidents	
Faint road markings		
Damaged bridges and guard-rails		
Scoured highway shoulders	Impairs integrity of road pavement	
↓	↓	↓
Increases safety hazards to road users	**Causes more road traffic accidents**	**Need for effective and timely road maintenance**
Road User Costs		
Issue/Problem	**Effect**	**Solution**
Clear link established between pavement condition and vehicle operating costs and embodied in transport investment models (e.g. HDM-4).	An increase in surface roughness causes vehicle operating costs to increase Significant additional costs incurred by road users when maintenance requirements are overlooked.	Identify, programme and control maintenance operations.
↓	↓	↓
Rate of pavement deterioration is often not contained, causing surface roughness to increase at an accelerating rate	**Additional costs to highway users**	**Use of an appropriate maintenance management system**
Life-Cycle Costs		
Issue/Problem	**Effect**	**Solution**
Feasibility and design strategies assume: that: (a) regular pavement strengthening will be carried out to arrest deterioration, (b) care will be taken to deal with localised imperfections as they arise (e.g. crack sealing).	Failure to control deterioration results either in an earlier requirement for strengthening or substantially increased costs of reconstruction.	Optimise investment by judiciously applying maintenance interventions to arrest rate of deterioration and to preserve structural integrity of each road link in the network.
↓	↓	↓
Assumptions often not realised in practice.	Economic penalties incurred which result in a need for premature reconstruction.	Use of an appropriate pavement management system.

All roads deteriorate with time. However, LVSRs are particularly sensitive to the vagaries of the physical environment so that timely and effective control of their deterioration becomes the key challenge to the management of road maintenance.

7.2.2 Deterioration Characteristics

Even with strict adherence to proper standards of construction, roads deteriorate with the passage of time. The rate of deterioration may vary greatly depending on the climate, the strength of the pavement and underlying subgrade, the traffic volume and axle loads. The wear and tear of road surfaces by traffic is aggravated by rainwater and by changes in temperature. Cracking occurs in the bituminous surfacing which, together with the ingress of rainwater, often leads to pavement failures.

Figure 7.2 illustrates how road condition deteriorates with time and how road life may be extended by controlled maintenance.

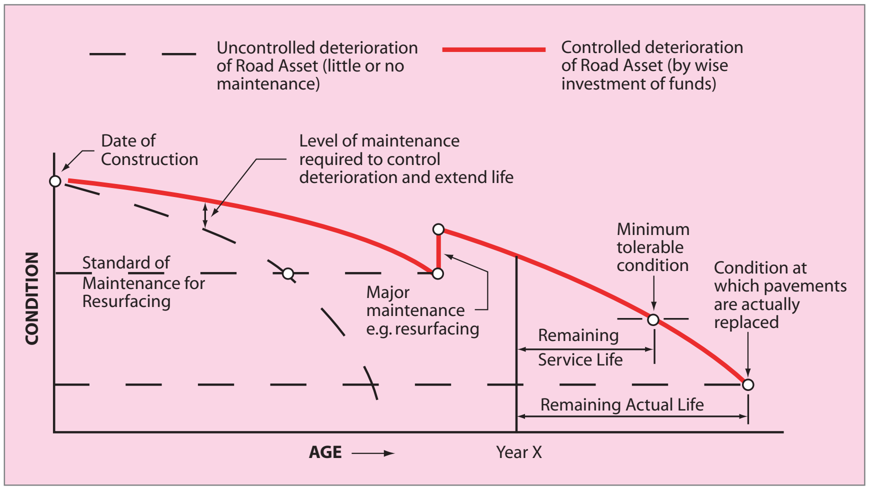


Figure 7.2 - Typical road condition deterioration with time

In Zimbabwe, the environmental component of roughness progression varied by a factor of almost 4, with low-volume roads built to lower cross sectional standards having the highest rate of progression and higher volume roads with standard designs having the lowest rate of progression. Corresponding crack initiation times and rates of crack progression were almost half and double those of standard designs respectively[1].

Of particular significance in responding to the maintenance requirements of LVSRs is the fact that, in contrast to more heavily trafficked roads, the proportion of total distress resulting from environmentally-related influences is very high, as illustrated in Figure 7.3[1].

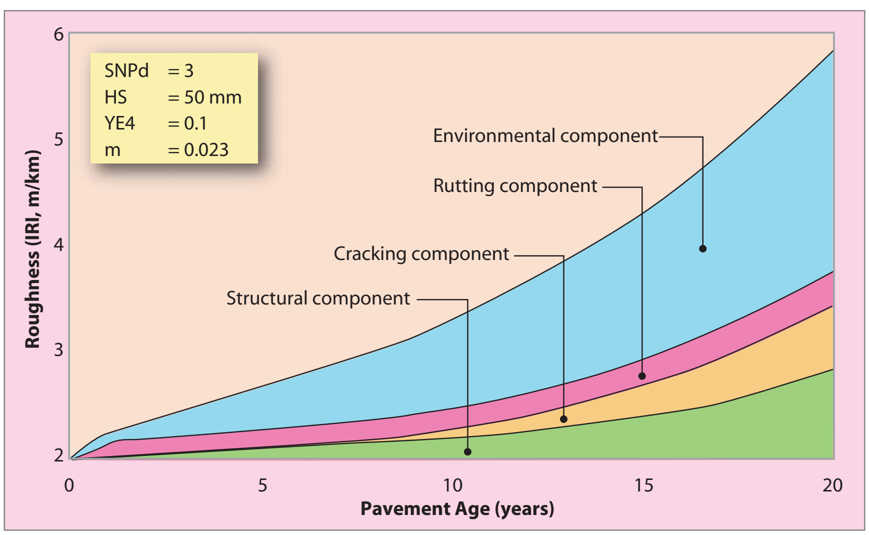


Figure 7.3 - Contribution to total predicted road roughness of different components for a low-medium volume paved road[1]

Whether the increased risk of deterioration is important in any locality will ultimately depend on the local climatic, traffic, pavement design, construction, workmanship and maintenance factors. Consequently, knowledge of local rates of deterioration will be vital. On the other hand, higher levels of deterioration and consequent reduced service standards can be tolerated from both an economic and user perspective. The lesson, therefore, is to appreciate the risks and manage these within the decision-making framework for justifying investment levels (see Section 5.4.6.)

7.2.3 Characteristics of LVSRs

As a general rule, LVSRs are built to lower geometric and pavement design standards than roads which carry higher traffic volumes. Thus they may be expected to have the following characteristics which have significant implications on maintenance operations:

- *A low cross-section profile* - thus making them more susceptible to moisture ingress and general deterioration, i.e. deterioration of the cross section which has serious impacts on overall performance.

- *Measures to protect the drainage system are usually minimal* - which often leads to increased erosion.

- *Thin bituminous surfacings are commonplace* - consequently, progressive embrittlement, poor construction or other causes of damage to the surface can easily lead to moisture ingress and consequent accelerated deterioration of the pavement.

- *The upper pavement materials are usually plastic in nature* - this can lead to a considerable loss in strength on wetting up, and accelerated deterioration under traffic load.

7.2.4 The Maintenance Challenge

The provision of adequate maintenance for LVSRs becomes even more difficult in an environment of limited funds, where resources become stretched to the limit to contain road deterioration.

LVSRs present a more demanding challenge than the more heavily trafficked HVSRs for their proper maintenance. Their characteristics, particularly their greater sensitivity to the vagaries of the natural environment, often mean that, in order to avoid rapid deterioration, maintenance must be scheduled and carried out more frequently and expeditiously than for HVSRs.

Attitudes to Maintenance
Historically, maintenance has been viewed as being un-attractive and mundane. As a result, it has not received the priority it deserves. This attitude has been strengthened by the preference of some aid agencies to finance capital rather than recurrent costs which has sometimes introduced a bias against maintenance (as recipient governments sought to use their limited funds in new construction, which would attract maximum foreign financial participation).

With maintenance often being seen as a public responsibility, funds allocated for maintenance have, on occasions, been diverted to other sectors that may be considered more deserving causes in the eyes of those involved in high level decisions. Through the 1980's and early 1990's, problems of this kind led to the deterioration of extensive parts of the main road network in many countries in the SADC region. This has contributed to the high transport costs - some four to five times higher than those in developed countries - thereby making the region globally uncompetitive. The cycle of the effects of inadequate maintenance is shown in Figure 7.4.

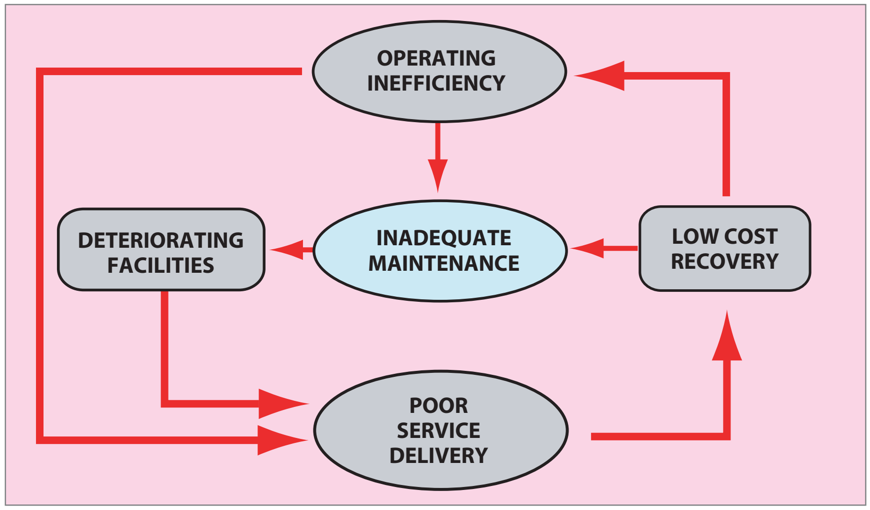


Figure 7.4 - The vicious cycle of inadequate maintenance

Funding of Maintenance

Although the concept of protecting the capital investment of road provision through timely financing of road maintenance is generally well understood, the application of this concept has presented formidable problems, primarily because of a lack of a sustainable source of funding.

In most SADC countries road maintenance expenditures are generally well below the levels needed to keep the road network in a stable long-term condition. Worse, budget allocations are often cut at short notice in response to difficult fiscal conditions, funds are rarely released on time and actual expenditures are often well below agreed budget allocations. This has led to a maintenance crisis in many countries where there is now a build-up of roads in poor condition. The net result is that the road transport sector is operating well below its optimum level, which has had an adverse impact on many other sectors of the national economy.

Box 7.1 - Maintenance backlog on the SADC main road network[2]

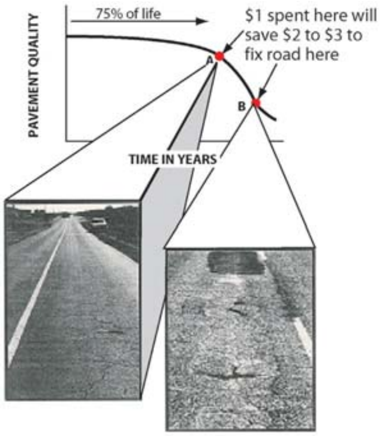
Recent studies indicate that about US$ 1.7 billion per annum (about 1 per cent of regional GDP) needs to be spent on regular maintenance of the region's roads, including a cycle of reseals and rehabilitation of paved roads. However, little more than one half of this amount is allocated.

GDP (1999)	Actual Annual Expenditure	Estimated Annual Requirement	Annual Shortfall	Back-log Maintenance
165,000	960	1,760	800	6,400

Note: All figures in millions of US $

It is also necessary to bring a significant kilometrage of main roads back to maintainable condition which is estimated to cost about US $6.4 billion.

The impact of inadequate maintenance



- *Drains get blocked (leading to flooding), verges become overgrown and obscure the driver's view, thereby increasing the incidence of road accidents.*
- *The surface deteriorates, gets rough, develops potholes and becomes difficult to drive on and vehicle operating costs increase.*
- *Soon, stretches of the road become impassable for long periods of the year.*
- *Eventually, and usually more quickly than most people realise, the road needs reconstructing, often at three to four times the cost of effective and timely maintenance.*
- *Where maintenance funds are not available, the road becomes abandoned, commerce and business stagnates, rural areas become isolated and condemned to remain poor without adequate communications.*

Inadequate Road Maintenance

New paved roads, if inadequately maintained, deteriorate slowly and almost imperceptibly during the first half to two-thirds of their service life, after which they deteriorate much more rapidly. Without timely maintenance, they simply break up and, as a result, the costs of operating vehicles - and of transporting goods - increase rapidly. Worse, vehicle operators who pay these costs, then pass them on to the general public and the cost of living increases.

In rural areas, where roads often become impassable during the rainy season, poor road maintenance has a profound effect on agricultural output. Poor roads and poor transport services also have adverse effects on the provision of health, education and other social services; these effects are not easy to quantify, but are of vital importance to the people living in rural areas and in helping to eliminate poverty in its widest sense.

Box 7.2 - The costs of poor road maintenance

A LVSR in good condition, carrying about 200 vpd, requires resealing, costing about $10,000 per km, every seven years to keep it in good condition. This has a net present value (NPV) discounted at 12 per cent over twenty years, of $7,000 per km. Without maintenance, the road will deteriorate from good to poor condition. This will increase vehicle operating costs by about $2000 per km which has an NPV, when discounted over twenty years, of $18,000 per km. The benefit cost ratio of a fully funded road maintenance programme is almost 3!

Poor road maintenance also increases the long-term costs of maintaining the road network. Maintaining a LVSR for fifteen years costs about $60,000 per km. If the road is not maintained and allowed to deteriorate over the fifteen year period, it will then cost about $200,000 per km to rehabilitate it. Thus, rehabilitating paved roads every ten to twenty years is more than three times as expensive, in cash terms, as maintaining them on a regular basis, and 35 per cent more expensive in terms of NPV, discounted at 12 per cent per year.

In quantitative terms, when a road is not maintained, and is allowed to deteriorate from good to poor condition, each dollar saved from not carrying out maintenance increases VOCs by $2 to $3. Thus, as illustrated in Figure 7.5, ***far from saving money, cutting back on road maintenance increases the costs of road transport and raises the net cost to the economy as a whole. This fact is a powerful one and one which roads agencies can use to convince government of the high cost that countries pay for inadequate funding of road maintenance.***

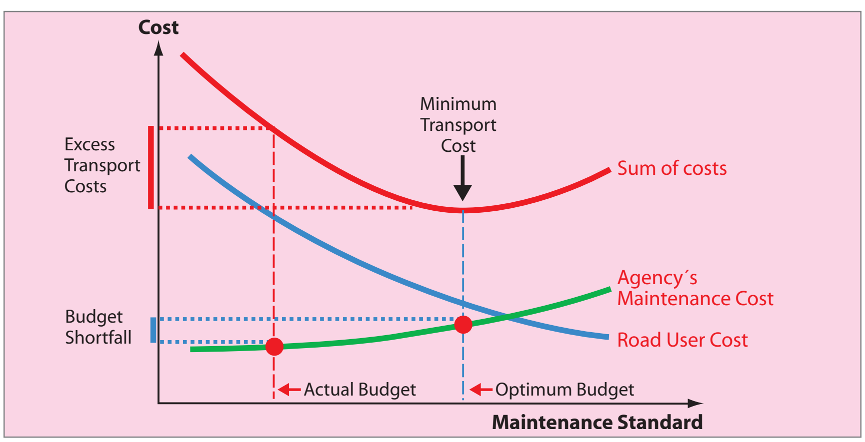


Figure 7.5 - Relationship between maintenance standard and transport cost

Vehicle overloading also has an adverse effect on road safety.

Overload Control

To protect the huge investment in road infrastructure, all SADC countries have promulgated Road Traffic Acts that stipulate permissible axle load and gross vehicle mass limits. These limits are meant to ensure that roads last for their full design life with normal maintenance expenditures. Unfortunately, overloading is rife in most countries, with rates of up to 50%. Such overloading causes not only a disproportionately high degree of road damage, because of the exponential relationship between axle load and road damage, but also contributes to the poor road safety record in many countries. Thus, overload control is particularly important on LVSRs.

Unfortunately, the current, traditional government-driven approaches to overload control have been ineffective in many countries for the following reasons:

- current systems provide a criminal response with low conviction rates
- in-house operation with low-paid staff is susceptible to corrupt practices
- there is no link between level of fines and damage to the road
- constraints in the criminal justice system result in low priority being given to overloading offences
- road authorities often have a limited role in regulating overloading
- current systems do not have the primary goal of preserving road infrastructure

There is, therefore, a need for a new approach and a vehicle loading reform strategy has been developed for the region which will form annexes to the SADC Protocol on Transport, Communications and Meteorology.
The main elements of this initiative are:

- introduction of a Regional Overloading Control Association
- introduction of a regional strategy for overload control
- operation of a self-regulatory system by transport operators
- decriminalisation of offenders by administering an overloading fee
- linking the level of the imposed fees to the actual cost of road damage
- outsourcing weighbridge operations to the private sector

7.2.5 Lessons Learned

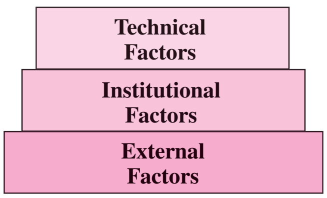
The ineffectiveness of maintenance operations, management and financing of LVSRs (and, indeed, of all roads) in the SADC region has been the subject of much study and investigation by international and local organisations. The worst cases of maintenance ineffectiveness have been found to occur in countries where some or all of the following conditions occur, not necessarily in order of importance:

- a weak institutional framework which suffers from high vacancy rates and reliance on contract personnel
- a large amount of maintenance work carried out through “force account” operations with reliance on plant and equipment provided from government plant pools “free of cost”
- lack of basic management systems and procedures which has compromised the ability of roads agencies to manage their road networks in a satisfactory manner

- poor regulation of various aspects of road management, including control of overloading
- inadequate involvement of the community in maintenance

It is apparent that the key issues raised above are predominantly social and organisational rather than technical. They support the widely emerging view in the SADC region that many of the endemic problems associated with inefficient and ineffective management of road networks are symptoms of a deeper problem. The real causes are weak or unsuitable institutional arrangements for managing and financing roads.

Hierarchy of management issues
(Adapted from Brooks et al., 1989)



Until the external and institutional frameworks are improved, it is extremely difficult to overcome the numerous technical and human resource problems which hamper attainment of efficient and effective management of road networks in the SADC region.

New approaches

As indicated in Chapter 2, through the SADC Protocol on Transport, Communications and Meteorology[3], the SADC region has embarked on a programme of road sector reform that has fundamentally changed the way in which road maintenance is undertaken and financed.

Box 7.3 - New approaches to road maintenance operations, management and financing in the SADC Region

A new approach to road maintenance in its various aspects is emerging in the SADC region. It is no longer being viewed as a mundane topic for second-rate engineers. Today, it operates in a changed environment and with a changed approach. It now holds a key position in roads agencies as a concept that espouses the need to preserve the value of the road asset, to provide improved service to road users and to contribute to environmental quality. Sustainable sources of road maintenance financing are increasingly being provided by road users.

7.3 Maintenance Management

7.3.1 Main Purpose

Maintenance management is essentially a systematic means of efficiently planning, programming, budgeting, scheduling, controlling, collecting data, monitoring, etc. In conjunction with the road planning, appraisal and design processes, it attempts to optimise the overall performance of the road network over time. At a practical level it aims to ensure that the correct activities are performed on the network at the right time, and to the desired quality. The challenge is to set policies which can contribute the greatest benefit to communities whilst supporting broad national goals.

The undertaking of the various inter-related activities associated with the management of maintenance can be facilitated by the use of an appropriate maintenance management system. Such a system must be well conceived and careful consideration should be given to pursuing a strategy for its development which should be based on methodologies, techniques and resources that are matched to local circumstances.

7.3.2 Inventory

A road inventory is necessary for any maintenance function. It is used as a basic reference for planning and carrying out inspections in relation to a location reference system. The essential elements include road nodes, route name and length, functional classification, type of pavement and surfacing.

The inventory is a set of information about the basic engineering characteristics of the road network and is vital for any management function. It defines the key features of each section of road and is an essential reference source for inspection and analysis. The content of the inventory should be directly relevant to maintenance management. When it is first drawn up it should be as simple as possible and need only contain information on the following items.

- route name
- functional classification
- section length
- type of surface and construction
- cross-section width

As the inventory is built up, further information can be added on all factors influencing the management activities. In addition, data about the distribution and engineering properties of soils will be useful in identifying possible sources of maintenance materials. Inventory data are expensive to collect and keep up-to-date. Generally, the inventory should be as simple as possible and not be overloaded with unnecessary information.

7.3.3 Components

There are four distinct and inter-related components of road maintenance which, together, comprise a management framework for successfully addressing the maintenance challenge[4]. As illustrated in Figure 7.6, these are: Planning, Programming, Preparation and Operations.

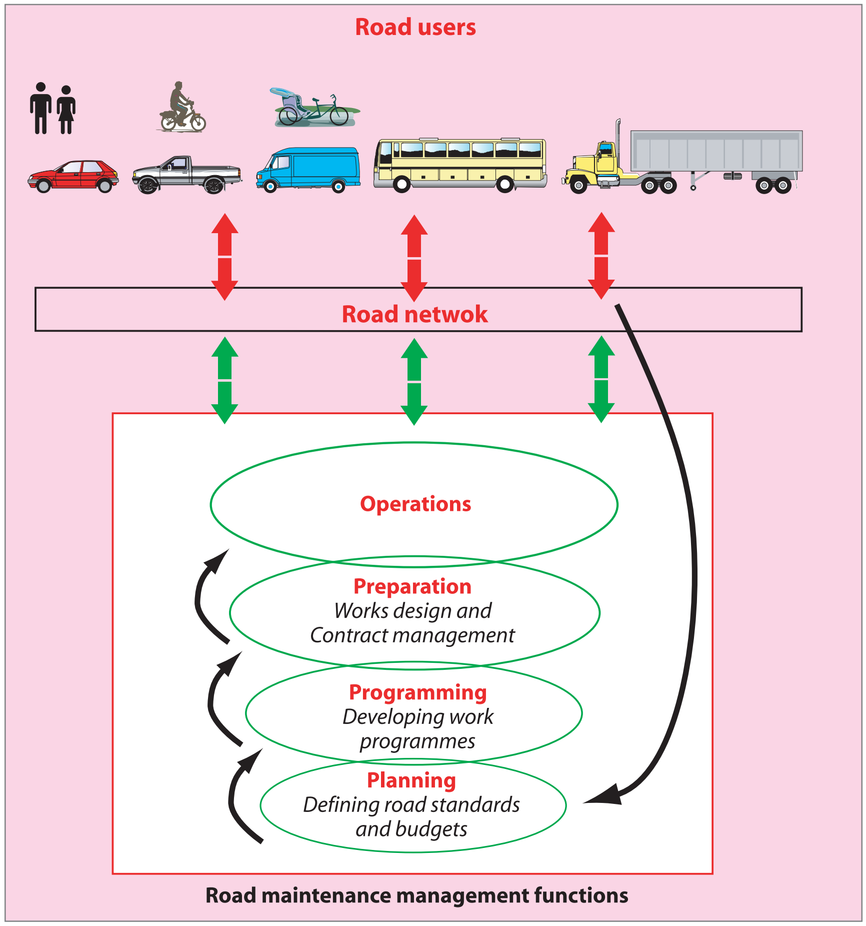


Figure 7.6 - Road maintenance management functions in relation to the road network and users [5]

Road maintenance management

At a practical level, road maintenance management aims to ensure that the correct activities are performed on the network at the right time and to the desired quality. The challenge is to set policies which can contribute the greatest benefit to communities whilst supporting broad national goals.

An implication of Figure 7.6 is that, if road maintenance at the point of delivery is to be optimised, then there is also a need to *optimise* the higher-level functions of planning, programming and preparation. However, the higher level functions will need to reflect the needs of road users on the network - an issue that has taken on added significance with the more commercialised approaches to road management currently being pursued in the SADC region in which road users have become *"customers"* of roads agencies which are now *"service providers'*. The challenge is to set policies which can contribute the greatest benefits to stakeholders whilst supporting broad national goals.

An important conclusion from the above is that any successful change to improve maintenance operations on SADC road networks should be driven from the needs and requirements of users and the network ("bottom-up") whilst supporting broader national goals of economic development and poverty alleviation. The remainder of this chapter focuses on such issues in the context of the LVSRs maintenance management cycle.

7.3.4 Management Cycle

Maintenance management strives to achieve maintenance policy objectives through a series of well defined, organised and executed functions. They relate to both long- and short-term decisions, and concern the whole network, sub-networks and individual lengths of road. The sequence of activities moves in a cycle that begins with planning and moves through programming, preparation and then operations in the manner shown in Figure 7.7[4,6].

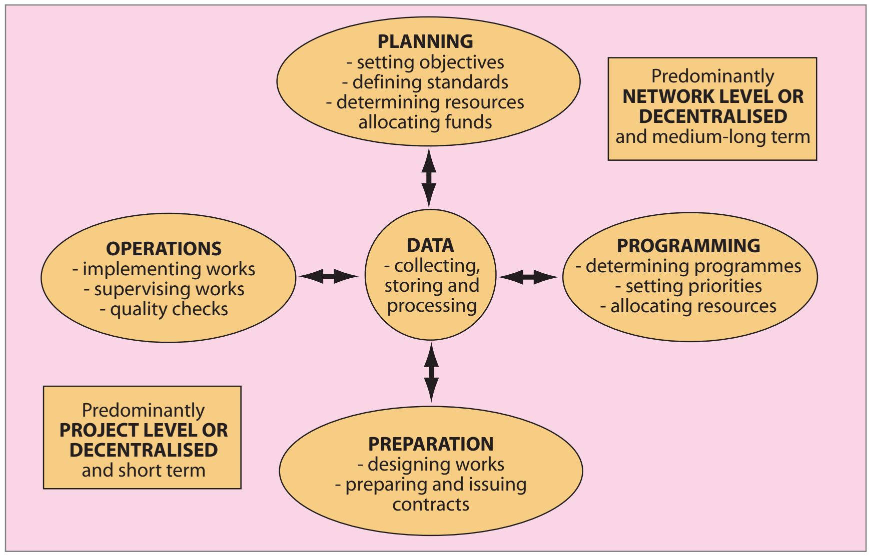


Figure 7.7 - The cycle and scope of maintenance management functions

The following issues are important, though not exclusive, to LVSRs:

- Effective management depends on the availability of sufficiently comprehensive data on all assets, traffic and costs.
- Participation, or effective representation, at the highest level, i.e. network planning, is usually essential to ensure that adequate resources are made available for maintenance.
- Whilst general programming and prioritisation might be done at a central level, more detailed programming will benefit from greater local knowledge and participation.

At each stage, procedures are required to guide staff in their duties, and should form the basis of more formal management systems which, for low-volume sealed roads, may comprise simple manual or spreadsheet-based systems.

Having defined in general terms the nature of maintenance, the following sections consider the operational environment within which maintenance resides with a view to offering solutions to its more effective delivery.

7.3.5 Maintenance Policy and Organisation

A policy framework is required to provide the context within which road maintenance is carried out in the SADC region. Maintenance policy would be expected to support Government policy in the roads sector. Increasingly, maintenance policy is now focusing on broader national issues pertaining to the attainment of socio-economic goals, greater involvement of the private sector and more attention to fulfilling users' expectations.

Box 7.4 - Typical Maintenance Policy Objectives for LVSRs

The following are examples of typical policy objectives which are essential for ensuring that maintenance is carried out in a sustainable way:

- Poverty reduction through employment creation and the related use of labour-based methods wherever feasible.
- Local community involvement in the planning and execution of maintenance of rural road facilities.
- Private sector involvement (local contractors) in road maintenance (rather than undertaking such maintenance by force account operations).
- The use of the most cost-effective rather than most technologically advanced approaches in carrying out road maintenance.
- Minimising the environmental impact of material resource developments by adopting Environmental Impact Assessments.
- The use of maintenance standards that balance life-cycle costs (construction, maintenance and vehicle operating costs).
- The use of simple contract documents appropriate for use by small contractors.

The SADC protocol on Transport, Communications and Meteorology envisages an institutional framework which clearly differentiates between the roles played by road sector stakeholders in policy formulation, policy delivery and works execution. The arrangements were illustrated earlier in the General Introduction to this Guideline (Chapter 2, Figure 2.5 - SADC institutional framework). This is a significant change from the previous arrangements which led, in one way or another, to the road maintenance crisis of the 80's and 90's.

Another significant change relates to the private sector, which is now involved as network maintenance contractors and network management consultants. The nature of the contracts may also be long-term and outcome-based, as opposed to the more traditional "schedule of rates" approaches.

Regional agencies, with a greater degree of autonomy than previously, can be expected to be involved in priority setting and communities might also deliver services at the operations level.

Table 7.3 - Functions of various road sector stakeholders

Function	Typical aims	Spatial coverage	Organisations concerned
Policy	Policy formulation. Formulation of strategic objectives. Defining standards.	Network-wide.	Ministry.
Strategic Planning	Determining resources to support defined standards and objectives.	Network-wide.	Roads Agency (HQ) with approval by Ministry policy advisors.
Programming	Determining the work programme that can be executed within the budget period and resource constraints, including local priorities.	Network-wide to Region or sub-network wide.	Regional Agencies or Consultant and Contractors and Communities.
Preparation	Design of works. Preparation and issue of contracts and works instructions.	Sub-network, Road-link, Section or project.	Regional Agencies or Consultants and Contractors.
Operations	Undertaking tasks as part of works activities.	Sub-network, Road-link, Section or project.	Contractors and Consultants and Communities.
Monitoring and Evaluation	Measuring achievements against performance, end product and financial targets.	Network-wide to project level.	Representatives of all functions, including Road Fund Board.

7.3.6 Maintenance Standards

In the constrained budgetary situations that prevail in most SADC countries, maintenance standards and associated levels of user service should be set, wherever possible, on the basis of minimising total transport costs over the life-cycle of the road link. If maintenance is carried out too frequently, or to a too high standard, the maintenance provided will be unnecessarily costly and resources will be wasted just as they will be if too little maintenance is carried out.

Badly potholed road.
Is this acceptable?
No

Road with occasional potholes which can be maintained through patching, but with a waterproof surface.
Is this appropriate?
Yes

Road in excellent condition.
Is this always affordable?
No

Figure 7.8 - Choosing appropriate maintenance standards

For LVSRs, the range of choices is typically as illustrated in Figure 7.8. In many cases the middle example will often provide the most appropriate solution, but this will depend on local circumstances and the extent to which it fits with the current views of policy makers and users, and those of engineers and planners.

The Engineer and the Planner will need to specify an appropriate standard for all types of maintenance and, importantly, to be able to justify this to policy makers and the paying public. They will also need to be flexible and to take into account local circumstances. Their responses may vary from a comprehensive, 'Full' maintenance strategy where the objective is to minimise life-cycle transport costs, to a minimum strategy which will help fulfil 'Basic' access standards. A strategy to minimize road user costs, which is the expensive option, is unlikely to be promoted by stakeholders.

Resealing is a typical periodic maintenance activity.

Typical examples of routine maintenance standards, intervention levels and work procedures, in relation to road function, are given in Table 7.4. Similar standards and maintenance strategies can also be developed for periodic maintenance. Many models exists for such analyses (e.g. HDM 4, RED) but their applicability becomes more and more questionable when road user savings are small relative to the cost of the road. In such situations, cost-minimisation strategies become a prudent alternative, *without compromising road safety.*

Table 7.4 - Typical routine maintenance standards

Activity	Standard		
	A	B	C
	Strategic/Primary roads **AADT >150**	**Secondary/Tertiary roads AADT < 150 and > 50**	**Secondary/Tertiary roads AADT < 50**
Grass cutting	Grass height ≤ 30 cm	Grass height ≤ 30 cm where sight distance must be maintained	As the need arises
Removal of obstacles	Clear carriageway immediately; Clear rest of road area and repairs within 5 days	Clear carriageway immediately; Clear rest of road area and repairs within 10 days	Clear carriageway immediately; Clear rest of road area and repairs within 60 days
Culvert clearing/ repairs	Clearing and repairs before wet season; Clear once a week during wet season; Repairs within 20 days	Clearing and repairs before wet season; Clear once every 2 weeks during wet season; Repairs within 30 days	Clearing and repairs before wet season and, when required, during wet season
Bridge clearing/ repairs	As above	As above	As above
Erosion control/ repairs	As above	As above	As above
Drain clearing	Clean out within 5 days when drain depth is reduced by > 20 %	Clean out within 10 day when drain depth is reduced by > 30 %	Clean out within 20 days when drain depth is reduced by > 50 %
Pothole repairs	Repair potholes within 2 days	Repair potholes within 2 days if > 5 potholes/km or during wet season, otherwise repair within 10 days	Repair potholes within 5 days if > 10 potholes/ km or during wet season, otherwise repair within 20 days
Surface patching	Repair within 2 days	Repair within 5 days	Repair within 10 days
Crack sealing	Seal all cracks before wet season starts; Seal immediately during wet season; At other times seal within 5 days if affected road section is > 10 m or if crack width is > 3 mm	Seal all cracks before wet season starts; Seal immediately during wet season; At other times seal within 10 days if affected road section is > 50 m or if crack width is > 3 mm	Seal all cracks before wet season starts; Seal immediately during wet season; At other times seal within 20 days if affected road section is > 50 m or if crack width is > 3 mm
Edge repairs	Edge drop should not be > 15 mm; Correct within 10 days	Edge drop should not be > 25 mm; Correct within 20 days	Edge drop should not be > 25 mm; Correct within 30 days

Note: Adapted from TRL (2003)[7]

Visual condition survey.

Measuring bearing capacity using Benkelman Beams.

Roughness can be measured by using rapid or slow measuring devices such as a Bump Integrator or Merlin device.

7.3.7 Assessing Needs

Road condition surveys are an important aspect of the maintenance process and are carried out to establish maintenance requirements and, subsequently, priorities. Such surveys are normally carried out in two stages:

- Network screening survey - in the first stage, an engineer or senior technician undertakes a drive-over survey of the network to identify those sections likely to need treatment.

- Detailed pavement testing - the second stage involves a small team, led by a technician, whose task is to determine the requirements for reactive and periodic works, and to identify those sections where detailed investigations are needed prior to carrying out renewal works.

Figure 7.9 gives a flow diagram of road condition surveys. Visual condition surveys, including a drive-over of the network, are normally adequate for LVSRs, with a detailed walk-over survey done selectively for sections appearing to need major works. Detailed pavement testing e.g. using a FWD, Benkelman Beam or DCP, is required for pavement rehabilitation design but this is not the main concern in this Guideline. The concept of Information Quality Levels (IQL)[8] have been developed with a level of detail that is appropriate for LVSRs.

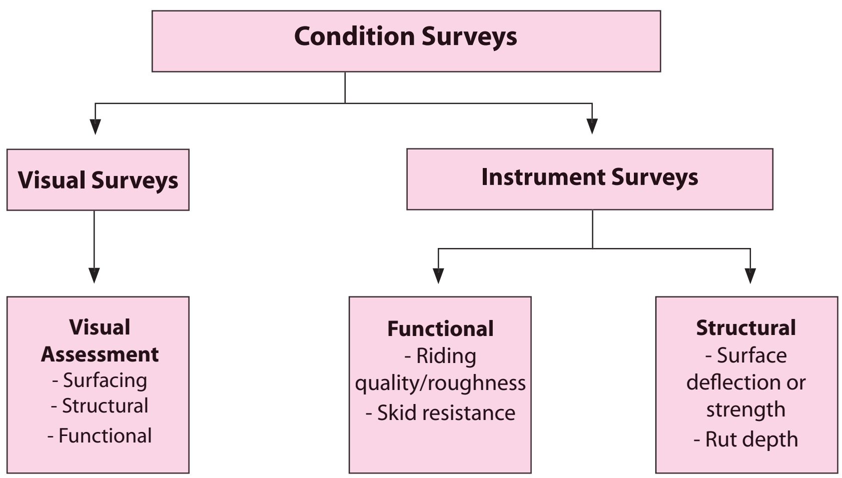


Figure 7.9 - Flow diagram of road condition survey tasks

Common types of road condition data collected during surveys are given in Table 7.5.

Table 7.5 - Condition data elements

Data Category	Data Elements	
Visual (to be followed, if necessary, by more detailed inspection and measurement)	• Texture • Surfacing failure • Surfacing cracks • Block cracks • Crocodile cracks • Longitudinal cracks • Transverse cracks • Pumping	• Aggregate loss • Binder condition • Bleeding/Flushing • Rutting • Settlement • Patching • Potholes
Visual and/or instrument	• Deflection (FWD or • Benkelman Beam) • DCP • Rut depth • Riding quality/rough-ness • Skid resistance • Surface drainage • Cross - section	• Laboratory tests • Side drainage • Shoulder condition • Edge break • Passability

It is preferable that direct measures for each type of distress are reported for maintenance management purposes rather than combining several distress parameters into a single index. This is because different types of distress often require different treatments. A combined index obscures the severity levels of the various distress types and therefore makes it difficult to identify optimum treatment. Nevertheless, a combined index, such as the Present Serviceability Index (PSI), can be useful for reporting the condition of roads to non-specialists, who are unlikely to understand the engineering importance of the different type of distress that may occur.

Irrespective of the road class, measurement of distress should be undertaken tri-annually, with the statistics presented in a cumulative frequency distribution for each road class, as illustrated in Figure 7.10. This can be used to illustrate the current condition of the asset in relation to target values and previous and current conditions.

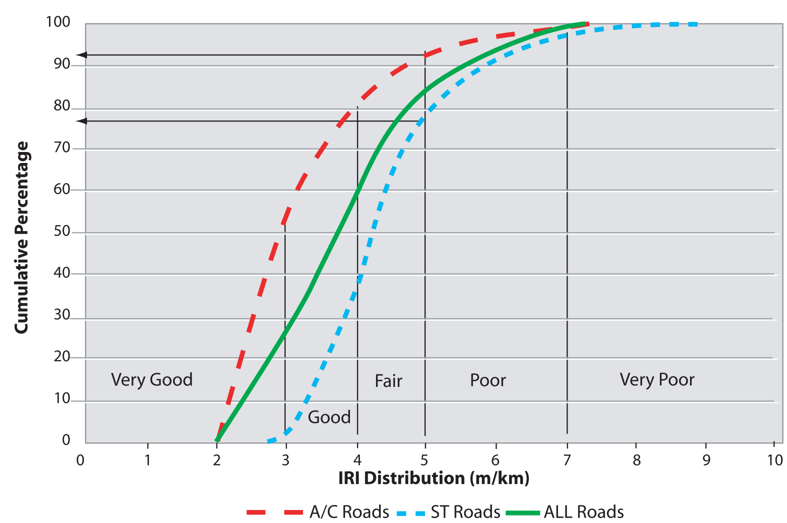


Figure 7.10 - Example of roughness distribution for different road classes

7.3.8 Determining Priorities

Even when standards have been developed on an economic basis or in support of policy objectives, the fact that budget allocations are invariably less than the desired amount means that choices must be made. The types of choices include whether to:

(a) delay investment until more funds are available
(b) lower standards
(c) perform certain activities in preference to others

Different approaches are available for prioritising works. Some depend on the type of road, works type and traffic levels, whilst others take account of issues such as the population served, economic indices, social indices and strategic importance. They are often applied differently to paved or unpaved roads and to high or low-volume roads.

Three approaches are introduced below that span the range of available techniques and may be used to complement each other. They address the range of issues and potential conflicts important for low-volume sealed roads. These are:

- Treatment choice method (TRL, 1987)[7].
- Cost effectiveness methods.
- Economic NPV and NPV/Cost methods.

Treatment Choice Method: In this method, funds are earmarked for 'essential' maintenance activities such as addressing emergency works, access restoration (over short stretches), drainage maintenance and asset preservation. Remaining funds are distributed to more heavily trafficked roads justifying more expensive treatments, with unfunded works being postponed or other budget sources sought. It is both simple and flexible, since the user can specify the order of importance based on local priorities. An economic underpinning does exist in that it is widely recognised that routine maintenance provides a higher economic return than an intervention occurring only after significant distress has already occurred.

Table 7.6 - Example of "Treatment Choice Method"

Hierarchy of maintenance activity	Priority							
	Traffic hierarchy							
	1	2	3	4	5	6	7	8
Traffic range (vpd)	Strategic	> 1000	500-1000	200-500	> 200	< 200	50-200	< 50
Surface type	P	P	P	P	UP	P	UP	UP
Emergency	1	7	8	9	10	11	12	13
Cyclic drainage	2	14	15	16	17	18	19	20
Reactive pavement work	3	21	24	27	30	33	36	39
Periodic preventative	4	22	25	28	31	34	37	40
Other cyclic/reactive	5	23	26	29	32	35	38	41
Overlay/reconstruction	6	42	43	44	45	46	47	48

Note: P = paved, UP = unpaved

Cost-effectiveness methods: These methods introduce other considerations into the prioritisation process that are not addressed by conventional transport economic approaches. These considerations include:

- magnitude of population served
- weighting for degree of poverty in the communities
- potential for agricultural or other development
- number of social and other services

This approach might best be applied to rural feeder or collector roads, where the geographical area which benefits from an improvement can be precisely defined. It also lends itself to application at a local level through the direct participation of representatives of various stakeholder groups. Reference should also be made to Chapter 3 in this regard.

Economic NPV and NPV/Cost methods: These methods are appropriate for relatively heavily trafficked roads relying on user benefits for economically justifying maintenance interventions. They are employed in models such as HDM-4 or RED which have been described in Chapter 3.

7.3.9 Management Systems and Tools

In the SADC region, where allocations to the roads sector have generally not kept pace with requirements, it is vitally important that scarce funds are allocated to competing components of the road system in an optimal manner. However, even with the best of intentions, the determination of such a balance cannot be competently assessed by traditional methods which generally relied on fixed standards, subjective judgement and intuition. Nor can appropriate funding and pricing strategies for promoting more efficient use of resources in the roads sector be developed. To this end, the use of an appropriately structured Road Management System can greatly assist roads agencies in managing and financing their road networks efficiently and effectively.

The main objectives of a Road Management System are to:

- Provide a systematic and structured means of developing annual work programmes, resource requirements and budgets based on optimum *economic standards*.
- Ensure an equitable distribution of funds over the country and enable priorities for allocations to be determined in a rational way when available funds are inadequate.
- Authorise and schedule work.
- Provide a system for monitoring the efficiency and effectiveness of maintenance works.

The potential benefits of efficient road management systems are well documented. However, few systems have been sustainable within developing environments. Current difficulties are partly a consequence of the substantial resources required to operate them effectively, particularly the basic data collection itself and the over ambitious expectations of users. Key elements, such as the importance of cost-effective standards, proven treatment selection and prioritisation methods and the quality of service delivery are often given insufficient attention.

Experience from the SADC region and elsewhere indicates that the 'institutional' dimension has often been sadly neglected and that, if the foundations and commitment required for sustainability do not exist, the systems will fall into disuse and become ineffective. This has been put into sharp focus throughout the region as a result of the road reform process and the resulting changes in responsibilities, which have clearer outcome-based objectives and require more transparency and accountability.

For a road management system to be sustainable, commitment from senior people is vital. However, complexity and excessive resource requirements, especially at the early stages, are serious risks. Sustainability is likely if a step-wise approach is adopted for its introduction, starting with a simple system requiring modest data collection in keeping with the current institutional capacity of the roads agency. An integrated modular design should be employed to facilitate future expansion and improvements and these should be introduced gradually as the operation of the system becomes institutionalised.

Specification of Road Management Systems (RMS)
The approach for developing a specification for a system for application to low-volume sealed roads, and most other categories of road infrastructure, should[6]:

- be simple, since this will ultimately retain a greater feel of transparency and comprehension by users
- specify the *scope* of the system and its component modules or sub-systems
- identify the prospective *users* of the system and their role in managing its various parts and the access they will require across the whole system
- confirm the *outputs* that its users will require
- select the categories of *data* and *models* required to produce the outputs, and how the data will be collected and processed

An example of a simple, basic RMS is shown in Figure 7.11.

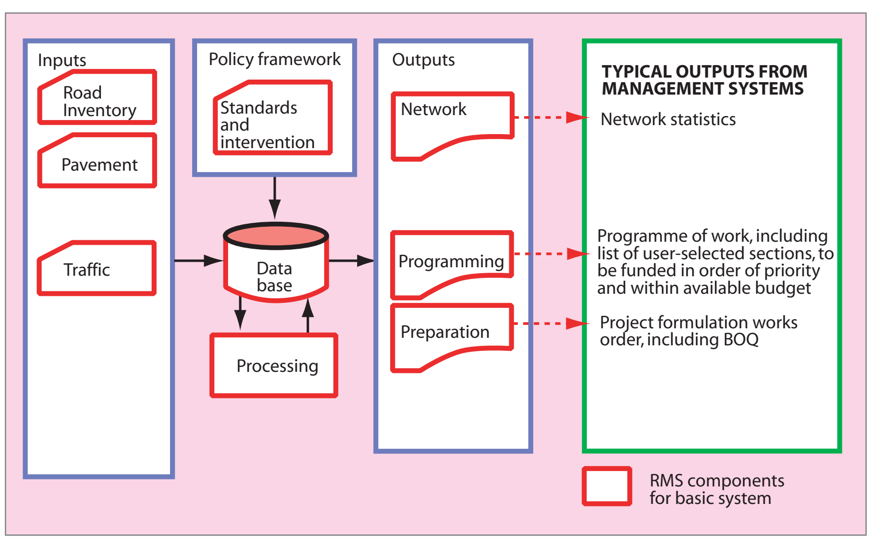


Figure 7.11 - Example of a simple, basic RMS

The scope and components (or sub-systems) typically include:

- A Network Information System at the core that is used to assemble, organise and store data about the network, including road inventory, pavement details, structures, traffic, finance (including budgets), on-going and planned activities, and resources.

- A number of Decision Support Systems (DSS) to assist in the tasks that form the management cycle.

Decision Support Systems produce *outputs* which inform management of decisions, whereas information systems simply list or present input data in tabular, graphical or map format.

The above approach tends to emphasise the overall purpose of the system, and de-emphasise the software and hardware considerations which, though important, are peripheral to the development of a system, at least in its early stages. This approach also emphasises user control, and places systems in their appropriate place.

Whether data are collected and presented in simple tables or spreadsheet formats, or manipulated in databases and processed through an analytical tool, the rules and processes employed should reflect the technical procedures described in the foregoing sections. More detailed guidance on system specification and example outputs are given in various source documents[5,6,7] and proprietary systems manuals.

Data Requirements

Probably the largest component of running costs for a Road Management System is that incurred in data collection. Thus, the type and quality of data to be collected will depend on what is actually needed and what can be realistically achieved. Only data which can be regularly updated and maintained should be collected and verified for consistency and completeness. To this end, the following criteria should be considered when selecting data items:

(1) *relevance:* having a direct influence on the required output

(2) *appropriateness:* both to the stage of planning and management process, and to the authority's capability to undertake the required data collection

(3) *reliability:* in terms of accuracy, coverage, completeness and correctness

(4) *affordability:* in both financial, and staff requirement terms

It is also important to select data acquisition technology that matches the requirements of the road agency. Choices to be made in the selection of data collection methods include:

- Mode of operation
  - manual, semi-automated or automated
  - pedestrian, slow or high-speed
  - independent or composite instrumentation
- Frequency, spatial coverage and spatial sampling of surveys

- Mode of administration
  - centralisation
  - audit process

The range of data quality and detail required, in terms of Information Quality Levels (IQL), depends on the management function and should also be matched with resources available. Guidance on various aspects of data management for road management systems is provided in literature on this subject[7].

7.4 Maintenance Operations

7.4.1 Organisational Roles and Models

Current and previous practice in many countries in the SADC region and, indeed, in most other countries in the world, has been to carry out maintenance (particularly routine maintenance) by direct labour i.e. labour permanently employed by roads agencies. However, this has proved to be inefficient in many countries and, in accordance with the SADC Protocol, there has been a gradual change in the execution of maintenance works towards the increased use of the private sector.

Roles

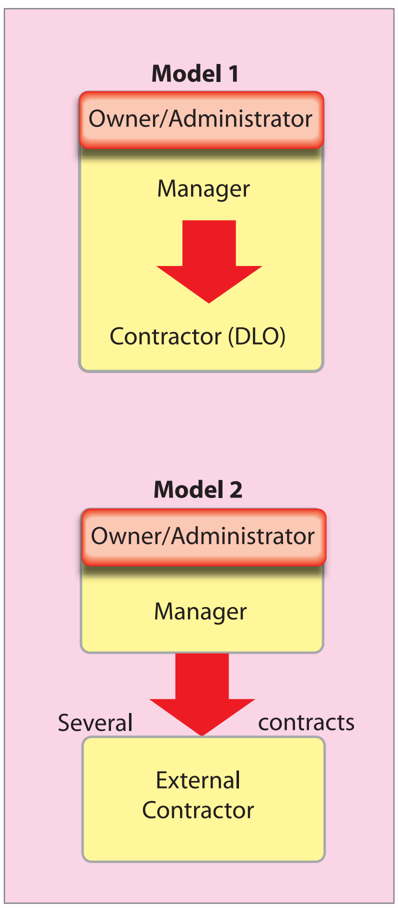
The terms used to describe the organisational roles which prevail in the SADC region are as follows[4]:

Owner: The organisation responsible for funding, establishing road policy and the legal and regulatory framework for management of the road network. Typically, this will be a ministry of transport or works acting as the *de facto* owner on behalf of the state.

Administrator: The organisation responsible for implementing policy and ensuring that the performance of the road network meets the overall political and economic aims of the owner. In many countries, this is referred to as the road authority or agency.

Manager: The organisation, responsible for specifying activities to be carried out, supervising, controlling and monitoring activities. In most situations, the manager role is combined with that of the administrator, but increasingly worldwide there is a move to appoint managers under contract (typically, engineering consultants).

Contractor: The organisation, responsible for delivery of operations by executing or undertaking works for the road administrator.

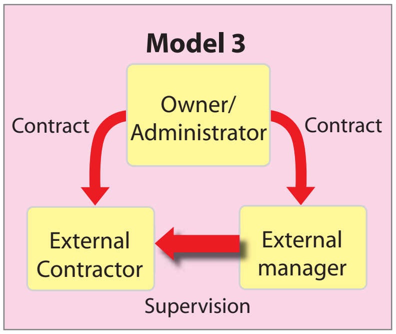


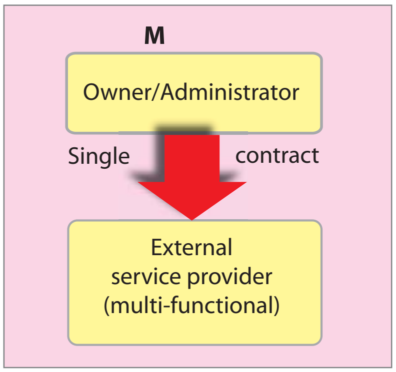
Models

Model 1 - In-house works unit (Direct Labour Organisation - DLO): This is the traditional model for undertaking routine and, occasionally, periodic maintenance works. In this case the administrator, manager and contractor are all part of the same organisation. In many cases, this will be the owner´s organisation, such as a ministry of public works.

This traditional approach is gradually being phased out in the SADC region as more and more agencies are becoming autonomous or semi-autonomous organisations with a greater separation of “client” and “supplier” roles within organisations.

Model 2 - Conventional contractor: In this model, the road administrator, who lets conventional civil engineering contracts to an external contractor for carrying out the works, takes the manager role. The model is widely used for carrying out development and periodic maintenance works but is less widely used for carrying out routine and special maintenance works.





Model 3 - Conventional contractor-consultant: In this model, the road administrator lets contracts for both the manager and contractor roles. Consultants typically undertake the manager´s role and have the task of supervising the work undertaken by contractors.

Many of the new Roads Agencies continue to employ this model, but with the Agency itself being bound by a "Performance Agreement" with the Owner Ministry. Their performance is monitored by a Road Board, or other independent body, which essentially fulfils an audit role.

Model 4 - Total service provision: In this model, a single contract is let by the road administrator to the manager who is responsible for providing services to the administrator. The manager organisation may choose whether to undertake the contractor roles itself, or engage contractors. There are few existing examples of this, although this type of arrangement is gaining favour.

7.4.2 Performance and Contractual Agreements

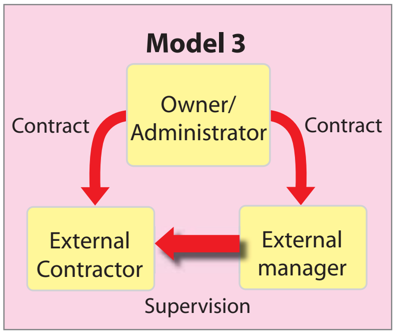
The change in circumstances requires a new set of agreements to be identified which are both legislative in nature, in that they transfer established responsibilities to a new organisation or responsible body, and contractual in nature. The changes also transfer a substantial amount of financial and technical risk to service providers, including road managers and contractors, and require new approaches for monitoring and evaluation. The appropriateness of the arrangements needs to be considered from the perspective of the supplier's ability to accept risk and to provide the necessary quality management. This will ultimately decide the scope of works which various providers can deliver.

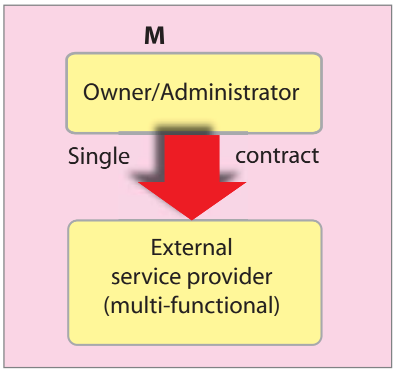
The characteristics of the various types of contract, in which their relevance in rural situations, is emphasised, are indicated below:

Day labour: This type is purely a supply-only contract, and could be extended to include plant and materials. It continues to be appropriate where contractor development and the scale of operations is small or uncertain. An appropriate example would be the supply of labour by 'lengthmen' contractors, perhaps organised through a community association, but with overall management vested in a local works department or managing agents.

Schedule of rates: This is the most common form of contract, (Model 2 above,) where the contractor is not subject to significant performance-based requirements, and undertakes a prescribed set of activities at specified intervals, or when conditions exceed 'intervention standards'. Rates are negotiated, or in some cases stipulated by the purchaser; the reason for the latter is related to the stage of 'commercialisation' in the sector. The quality of workmanship will be specified, *and work planning and method guidelines* may be provided to ensure consistency in approach to each operation. Many road authorities in the region have adopted such guidelines.

Performance-based, short-term: Performance-based contracts require the contractor to accept the greater part of the risk and to plan and specify the long-term maintenance needs to satisfy the outcome-based performance specification of the Client, and are usually lump sum contracts. The scope of work includes routine and emergency works and can extend to include





Model 3 - Conventional contractor-consultant: In this model, the road administrator lets contracts for both the manager and contractor roles. Consultants typically undertake the manager´s role and have the task of supervising the work undertaken by contractors.

Many of the new Roads Agencies continue to employ this model, but with the Agency itself being bound by a "Performance Agreement" with the Owner Ministry. Their performance is monitored by a Road Board, or other independent body, which essentially fulfils an audit role.

Model 4 - Total service provision: In this model, a single contract is let by the road administrator to the manager who is responsible for providing services to the administrator. The manager organisation may choose whether to undertake the contractor roles itself, or engage contractors. There are few existing examples of this, although this type of arrangement is gaining favour.

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Performance-based, short-term: Performance-based contracts require the contractor to accept the greater part of the risk and to plan and specify the long-term maintenance needs to satisfy the outcome-based performance specification of the Client, and are usually lump sum contracts. The scope of work includes routine and emergency works and can extend to include periodic works, the need for which requires approval processes to be actioned by the Client. In many cases, the contract incorporates provision for periodic works, thus reducing the need for new procurement processes within the contract term thereby providing a greater guarantee of workload for the contractor. Such contracts are generally termed *Network Maintenance Contracts* (in Australia) or *Term Maintenance Contracts* (in the United Kingdom) and are usually managed according to Model 3 above.

Performance based, long-term: These extend the responsibilities to the service provider, who provides a 'total service' as illustrated in Model 4 above. The long-term nature of these contracts means that substantial planning and management capability must reside within the service provider. The works include all maintenance activities and rehabilitation. Key Performance Indicators need to be set by the Client for long-term and short-term attributes. It is then the contractors who specify how the targets will be achieved and this will be incorporated into their tendered proposals.

Contracts of this kind are becoming common-place in Australia and New Zealand[5], with entire rural road networks managed under such arrangements in Western Australia and parts of New Zealand (10% increasing to 30% in future). Independent auditing of achievement becomes a Client responsibility. These contracts allow considerable innovation on the part of the Contractors.

7.4.3 Acceptance of Risk

The form of contract defines each party's responsibilities and allocates the various risks between them. Risks can be grouped according to those that affect:

- Quality - the possibility of the work not meeting the requirements of the client.
- Cost - the possibility of the cost of work being different from that predicted.
- Time - timely delivery is less of an issue for maintenance than for construction projects, and is closely related to cost.

The political trend in recent years has been to transfer as much risk as possible to the private sector, but experience has now shown it is best allocated to the party most suited to cope with that risk[9,10]. In countries where maintenance has traditionally been carried out by in-house units, the private sector will often not be in a position to take on significant new risk, nor will the road administration be in a position to manage the private sector properly. Table 7.7 illustrates issues of risk allocation for road maintenance.

Table 7.7 - Contracting strategies and allocation of risk

Issue	Client to manage risk	←	→		Contractor to manage risk
Type of contract	Hourly rates	Single activity	Grouped activity	Performance based (short)	Performance-based (long)
Payment method	Cost reim-bursable	Target cost	Schedule of rates		Lump sum
Term of contract	Short term	←		→	Long term
Packaging	Many small contracts	←		→	Few large contracts

LBM

Boiling of bitumen on road side and later mixing with aggregate, is an appropriate method for patching potholes in a sealed road.

LBM

Road marking using labours have been successfully used in many SADC countries.

7.4.4 Increasing the Use of Small-scale Contractors

A range of clients and contractors of differing capacity are usually present in all countries. Different sized contractors will respond to different types of client: for example, medium- and large-scale contractors will often have little interest in low-cost, dispersed rural routine maintenance contracts. In addition, many smaller local contractors might only be working currently in the building sector. A contractor development programme would enable them to compete for work in road maintenance and might achieve the objectives of increased use of labour-based methods and increased local employment in such areas. This has been done in some countries. The use of local contractors and scope for labour-based maintenance, community involvement and responsibility has been dealt with in some detail in road maintenance policy seminars as part of the Road Maintenance Initiative (see Bibliography.)

Community Contracting

Many maintenance works offer possibilities for community participation and contracting, that are often not fully exploited. However, this is only likely to happen if:

- the infrastructure concerned is of direct benefit to them
- a sustainable institutional framework exists
- initial external inputs are made available for system development, funding, demonstration and training

Participation in community contracting initiatives implies stakeholder involvement in the planning, organising and implementation of the works. To this end, community bodies decide on local priorities and become responsible for managing the execution of the maintenance works by agreed means (e.g. through local contracts, paid labour/unpaid labour freely provided by the community with material support etc.).

Ultimately the successful involvement of small contractors or communities in carrying out maintenance works, by using labour-based methods where feasible, is important as a means of creating employment and helping to alleviate poverty. Fortunately, there are a number of manuals and guidelines available which deal with the development of small contractors employing labour-based techniques, including an introduction to business principles[11].

7.5 Summary

The key points arising in this chapter are:

1. Largely as a result of inadequate funding, the provision of satisfactory road maintenance still remains an elusive goal in many countries. The net effect is poor road conditions, high operating costs and an adverse impact on national economies.

2 The key maintenance challenges are predominantly political, social and institutional rather than technical.

3. The road sector reform process currently being pursued in the region, including the establishment of dedicated road funds, is critically important for the sustainability of maintenance funding. In this regard, the recommendations of the SADC Protocol on Transport, Communications and Meteorology should be implemented.

4. The pursuit of sustainable maintenance policies through the use of labour-based methods, where cost-effective, and the involvement of local communities and small contractors, is crucially important as a means of employment creation and are directly linked to poverty alleviation.

5. The lack of a systematic and structured approach to road maintenance results in inefficient and ineffective utilisation of scarce funds. However, the use of elaborate and complex management systems should be avoided and, instead, simple systems which are appropriate to local conditions should be introduced and implemented gradually.

The subject of road maintenance and its management aspects that are essential for the preservation of the LVSR network as well as other influencing factors, such as vehicle overloading, have been covered in this chapter. The potential benefits to be derived from the recommendations contained in this chapter and earlier chapters of this Guideline will only be realised through implementation, which is discussed in Chapter 8.

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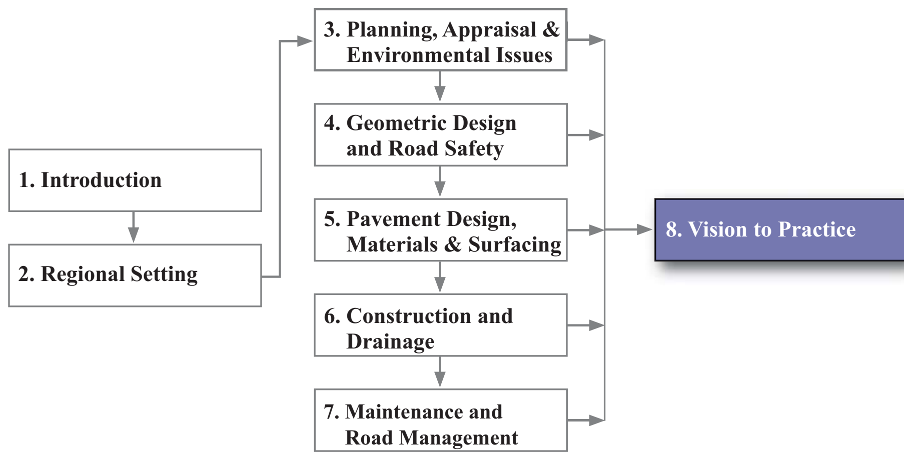
Chapter 8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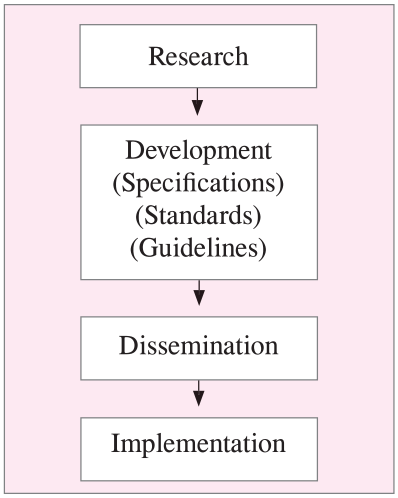
Vision to Practice

8

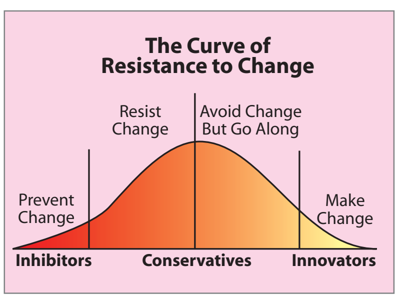
8.1 Motivation

There has been a very strong motivation for preparing this Guideline on Low-volume Sealed Roads in the SADC region. In essence:

- Many aspects of LVSR provision have stemmed from technology and research in Europe and the USA in environments very different from that prevailing in the SADC region.
- Whilst changes have inevitably occurred in the region, much of the basic philosophy concerning LVSR provision remains unchanged, as have many of the norms and standards to be found in guidance documents, which have not been revised for many years.
- A significant amount of research work spanning some 20 - 30 years has been carried out in the region by a number of specialist organisations, collaborating country agencies and, in some cases, by country agencies themselves.
- Much of the research has been aimed at low-volume secondary and feeder roads including planning, appraisal, design, use of local materials, surfacing techniques, construction methods and finance for maintenance. Where implemented, the results of this research have invariably been highly beneficial and cost-effective.
- Unfortunately, there is still a general tendency to use a conventional approach to provision of LVSRs that is often perceived to be “safe”. As a result, few of the results of relevant research have been put into practice and the potential benefits of so doing have not been gained.



Moving technology from the research environment to an operating environment will involve considerable technology transfer effort and resources to overcome various obstacles to implementation.



"There is nothing more difficult to take in hand, more perilous to conduct or more uncertain in its success, than to take the introduction of a new order of things, because the innovator makes enemies of all those who prospered under the old order, and only lukewarm support from those who would prosper under the new".

Machiavelli, The Prince (1513).

8.2 Pathway to Implementation

The benefits of the Guideline will only be achieved if the approaches recommended are implemented. However, the path from research to implementation is a tortuous and time-consuming one. It has been estimated that, in engineering, in each of the steps in the pathway that begins in obtaining funding for research through to implementation, the magnitude of difficulty increases by a factor of between 2 and 8. These activities include carrying out the research, processing the results, developing standards, disseminating the information, right through to actual implementation. Thus, it can be quite difficult to get the results of engineering research put into practice, despite the evidence that very large savings can accrue where this has been done.

The implementation stage can be accelerated by understanding the process that is involved in technology transfer, identifying the likely obstacles and adopting a strategy that seeks to mitigate them. In broad terms there are five stages to the process of innovation[1]:

Stage 1: Idea generator - the initial perceived need for developing the Guideline.

Stage 2: Technology generation, adaptation and transfer - which has been achieved by raising awareness of the results of research carried out in the region, the adaptation of appropriate standards and the knowledge shared in the development of the Guideline.

Stage 3: State and local roads agencies - the importance of "buy-in", which has been achieved through the process of stakeholder involvement in the compilation of the Guideline.

Stage 4: Specifications and contracts - the modification of conventional specifications and contract types to suit local conditions; the important role of contractors in embracing the new approaches as embodied in project applications.

Stage 5: Benefits - the substantial potential benefits to be gained by implementing the recommendations in the Guideline.

The production of this Guideline forms a major part of Step 3 as well as contributing to parts of Steps 2 and 4. This chapter is concerned with the pathway from here to full acceptance and implementation. The various obstacles and associated problems that remain and suggestions for overcoming them are discussed below.

8.2.1 Political

Government Policy: The road transport sector cannot be properly planned without reference to overall government transport policy. For effective planning, SADC governments need to take a comprehensive view of the whole transport sector, with road sector policy being designed to meet the wider social and economic goals of each country.

It is important that the key messages from this Guideline on the benefits to be derived from LVSRs are included in the debate leading to the development of a policy document. The policy should cover such issues as poverty alleviation, employment creation, technology choice, etc. The outcome of this process will dictate the type of planning system that is most appropriate.

In one SADC country, the use of a slurry seal on a low-volume access road was politically over-ruled because in an adjacent constituency the more traditional chip seal had been used on a similar access road and was perceived as being of a "better" standard.

Acceptance of new techniques requires open mindedness and a willingness to learn from planners and engineers who must apply it. It also requires the political will to resist pressure from vested interests and make the best use of the resources that they have at their disposal.

Political and Public Perceptions: The intense competition for scarce public funds makes it imperative that appropriate, cost-effective standards are adopted at all times in the provision of LVSRs. This may well imply the use of lower, but nonetheless appropriate, standards on these roads. However, such standards can still provide a satisfactory level of service with no compromise on road safety.

It is important that the public and political authorities accept the standards adopted for LVSRs. However, their perceptions as to what is an appropriate standard of pavement or surfacing can adversely affect technical decisions. Very often, such perceptions are conditioned by standards adopted for high volume trunk roads; a lower, albeit more appropriate, standard on a LVSR is often perceived to be "sub-standard" and, hence, unacceptable.

More effort needs to be expended on educating politicians and the general public as to the basis on which technical standards are determined so that they are more readily accepted. Ranking policy changes according to their political costs and benefits can help policy makers obtain support from politicians and the general public.

Vehicle overloading is still rife in the SADC region with estimates ranging from 10 - 50%. The costs of such overloading has been estimated to run into millions of dollars.

A 22% overload from 82 to 100 kN will, in broad terms, increase the damaging effect on a pavement by a factor of 2.5 and reduce the pavement life by a factor of 0.6.

Axle Load Control: Inadequate axle load control remains arguably one of the most serious challenges faced by road authorities in the SADC region. As indicated in Chapter 5 of the Guideline, pavement performance is critically influenced by traffic loading which, in turn, controls the life of the pavement. LVSRs are normally constructed of lighter (thinner) pavements using naturally occurring materials that are often very sensitive to the impact of overloading. This makes them particularly susceptible to overloading which has an adverse and disproportionate effect on pavement life. Thus, overloading is not only an increased risk to the road, including bridges, it is also not justified on economic grounds. A more determined effort should be made to control overloading.

Effective control of overloading requires a strong political will which is sometimes not evident. The move towards new methods of overload control, as contained in the SADC Memorandum on Vehicle Loading, provides a strategy Control of Overloading, which should be implemented by all countries as soon as possible.

Risk: The need to adopt more appropriate standards and specifications in the construction of low-volume road pavements has been clearly recognized in the SADC region for some time. However, whilst there are many examples of the successful adoption of such a strategy, few are well documented and, until relatively recently, the conditions necessary for successful performance were not adequately defined. Thus, there has been an understandable reluctance, particularly by consultants and donors from outside the region, to utilize non-standard materials because of an undoubtedly greater perceived risk of problems or even failure.

Fortunately, the results of research undertaken in the region over the past 20 years make it possible to utilize local resources with greater confidence. Moreover, risks can be mitigated by ensuring that standards/specifications apply to local environments.

The perceived risks associated with the use of non-standard materials and non-traditional designs can now be sensibly managed and a larger proportion of unsurfaced roads can be economically surfaced without additional risk.

8.2.2 Social

Appropriate labour-based strategies utilise the dual output of infrastructure provision whilst creating employment. Labour-based methods do not imply the elimination of plant but rather selective replacement. Nonetheless, such methods have a relatively higher potential for employment creation (typically up to four times more than equipment-based methods). Road infrastructure provision offers one of the highest employment potentials compared to other sectors. In the process, there is NO compromise on infrastructure specifications such as fitness for use and purpose.

ASIST Bulletin No. 11 2000.

Employment creation: More and more governments in the SADC region are promoting the use of labour-based methods as an alternative to the more traditional plant-based operations as a means of combating high unemployment levels. In this regard, road programmes that maximize the use of surplus manpower that might exist in a rural community are more likely to engender a positive attitude to the future maintenance of the road than programmes that are plant-based and require the import of a limited amount of skilled manpower.

Despite the above, negative perceptions still persist in some SADC countries that such approaches are uneconomic, time consuming and sub-standard.

Where labour-based operations are indicated, government will need to make a clear policy commitment for change. This will call for special institutional arrangements, comprehensive planning as well as effective managerial and administrative systems and procedures.

8.2.3 Institutional

The institutional framework of roads sector organisations in the SADC region critically affects all aspects of LVSR provision. Historically, traditional approaches to the management and financing of road infrastructure have proved to be unsuccessful. Fortunately, the agreed SADC institutional framework for management and financing of roads offers a promising alternative to traditional approaches and, where implemented, has begun to show positive results.

Where the recommendations of the SADC Protocol on Transport, Communications and Meteorology that deal specifically with road management and financing have not yet been implemented, Governments in the SADC region should accelerate the reform process.

8.2.4 Technical

Use of inconsistent, inappropriate standards should be avoided and, instead, regional standards should be promoted by governments and donors.

Technical Standards: The consistent application of appropriate technical standards and design methods is critical if cost-effective, sustainable solutions are to be obtained. In the past, there was an understandable tendency in the SADC region to rigidly apply imported standards, specifications and geometric and pavement design methods as “best practice” simply because there was little alternative other than taking an unquantified risk in using untried materials and design methods.

With the wealth of research and development work undertaken in the region during the past three decades, new, "indigenous" standards, specifications and pavement design methods have now emerged in a number of innovative ways on the basis of quantified evidence. Nonetheless, due sometimes to donor insistence or to lack of awareness of the existence of regional standards, there is still a tendency in some countries to use imported standards.

The time has come for government policy to stipulate that where regional standards, including specifications and design methods exist, they should be used in preference to imported standards.

8.2.5 Economic

The results of research have shown, quite unequivocally, that adoption of the methods described in this Guideline result in low-volume roads that are less expensive to build, are no more expensive to maintain and reduce the costs of operating both motorised and non-motorised transport during their service lives. Thus, both agency costs and total (life-cycle) costs are reduced. Furthermore, although economic assessments cannot readily take into account social benefits, if these are included, the benefits of following the principles advocated in the Guideline should be obvious. Nevertheless it is necessary to demonstrate this repeatedly and as clearly as possible for the benefit of administrators, economists and others in authority who should not be expected to be conversant with the engineering principles involved in road building and maintenance.

Research should be undertaken to develop improved appraisal methodologies for LVSRs so as to take better account of the socio-economic benefits that are often a large component of the total benefits.

8.2.6 Financial

The financing of road building and maintenance has been mentioned frequently in the Guideline. The main challenge is to secure sufficient funding both to maintain the existing network and to accommodate the extensions to the network that are deemed to be necessary for rural development and for the attainment of poverty reduction goals.

The SADC Protocol on Transport Communications and Meteorology has addressed comprehensively the issue of road financing and the associated institutional arrangements necessary to secure sustainable funding to maintain road networks in the region. The measures recommended in the Guideline support the goals set out in the protocol.

In those countries where Road Funds have not yet been established, the Governments concerned should expedite their creation.

8.2.7 Environmental

The continued use of large amounts of gravel is not only causing serious environmental problems in the SADC region but is also unsustainable in the medium to long term. This provides a strong impetus for adopting the strategies that are promoted in the Guideline which seek to improve the "environmental" performance of the road transport sector. This can be achieved, for example, through more extensive use of local materials, use of low-cost road surfaces, preservation of resources of high quality stone, cost and safety conscious design, consideration of non-motorised traffic, community participation in planning and many more.

The establishment of a government body to address environmental issues, including those associated with road provision, should also be promoted in the region.

8.3 Vision to Practice

The technology transfer effort, which is so essential for the successful implementation of the Guideline, has encompassed the following activities leading to the production of the Guideline:

- Early involvement of stakeholders in the research planning phase to ensure that the Guideline responds to user needs.
- Continuous involvement of stakeholders in the compilation of the Guideline through their participation in a number of regional workshops.

Other aspects of the technology transfer process that will require consideration and possible external support to ensure successful implementation include:

- Technical assistance to support the implementation of the Guideline.
- Technical staff training, where in-house staff do not have the required expertise, and training to address internal resistance to change.
- Changes to country standards, design manuals and specifications needed to accelerate the implementation of the Guideline.
- Monitoring of acceptance, adoption, refinement and satisfaction amongst users of the Guideline.

By its very nature, the Guideline is aimed at all stakeholders in the rural transport system but the primary target audience are those who are in a position to foster change and to implement the ideas presented in the document.

For more information on the topics herein, the reader is encouraged to refer to the bibliographies in each chapter. Additional references can also be obtained by contacting the organisations listed in Appendix B.

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List of Useful Organisations

American Association of State Highway & Transportation Officials (AASHTO)
AASHTO is a not-for-profit, nonpartisan association representing highway and transportation departments in the USA and Puerto Rico. It represents the five transportation modes of air, highways, public transportation, rail and water. Its goal is to foster the development, operation and maintenance of an integrated national transportation system by advocating transportation policies, providing technical services, demonstrating the contributions of transportation and facilitating institutional change.

444 North Capitol Street N.W., Suite 249	T: +1 (202) 624 5800
Washington DC 20001	F: +1 (202) 624 5806
USA	E: info@aashto.org
	www.transportation.org/aashto/home.nsf/FrontPage

ASTM International
ASTM International is a not-for-profit organisation that provides a forum for the development and publication of voluntary consensus standards for materials, products, systems, and services. These standards are an important part of the information infrastructure that guides design, manufacturing, and trade in the global economy. ASTM International has more than 20,000 members from over 100 countries representing producers, users, consumers, government and academia.

PO Box C700	T: +1 (610) 832 9585
100 Barr Harbor Drive	F: +1 (610) 832 9555
West Conshohocken	E:service@astm.org
PA 19428-2959	(Customer service)
USA	www.astm.org

Australian Road Research Board (ARRB) Transport Research
ARRB is the leading Australian provider of transport-related research and technical services. It has a pool of experienced researchers, engineers, laboratory technicians and support staff and has particular expertise in infrastructure asset surveying and management, road safety and traffic engineering and transport policy and management. ARRB works in many countries throughout Asia, Europe and the Americas with a variety of customers, including international aid agencies, national and local governments, state road authorities and construction, transport and mining companies.

Head Office	T: +61 3 9881 1555
500 Burwood Highway	F: +61 3 9887 8104
Vermont South	E: info@arrb.com.au
Victoria 3133	www.arrb.com.au
AUSTRALIA	

Austroads

Austroads is the association of Australian and New Zealand road transport and traffic authorities. Its purpose is to contribute to improved Australian and New Zealand transport by developing and promoting best practice for the safe and effective management of the road system, providing professional support and advice to members, assessing and developing Australian and New Zealand standards and managing the National Strategic Research Programme.

PO Box K659
Haymarket
NSW 2000
Australia

T: +61 2 9264 7088
F: +61 2 9264 1657
E: austroads@austroads.com.au
www.austroads.com.au

Council for Scientific and Industrial Research (CSIR)

CSIR is a scientific and technological research, development and implementation organization and plays a part in the development of South Africa as a nation and in the Southern African Development Community. One of eight operational divisions, Transportek offers specialist expertise in the fields of transportation research, traffic management, transport infrastructure and technology and information management, contractor development and rural and accessibility planning.

PO Box 395
Pretoria 0001
South Africa

T: + 27 12 841 2911
F: +27 12 349 1153
E: webmaster@csir.co.za
www.csir.co.za

Department for International Development (DFID)

DFID has a large programme of development assistance and also commissions research and dissemination projects with a transport theme. DFID also has a website whose purpose is to raise awareness of the importance of transport for development, within the context of developing countries. Many documents can be downloaded from this website. The address is www.transport-links.org

1 Palace Street
London SW1E 5HE
United Kingdom
Public Enquiry Point

T:P (within the UK):
0845 300 4100
T (outside the UK):
+44 (0)1355 84 3132
F: +44 (0)1355 843 632
E: enquiry@dfid.gov.uk
www.dfid.gov.uk

ILO – Advisory Support, Information Services and Training (ILO/ASIST)

The International Labour Organisation (ILO) is the UN agency which seeks the promotion of social justice and internationally recognised human and labour rights. The ILO has a unique tripartite structure with workers and employers participating as equal partners with governments. ILO/ASIST, part of the ILO's Employment-Intensive Investment Programme, seeks to contribute towards the alleviation of poverty through the use of local-level planning methodologies and employment-intensive strategies in the provision of rural and urban infrastructure. ILO/ASIST has two Regional Programmes, run by the following offices, and publishes a regular *Bulletin*.

ASIST – Asia Pacific
UN Building 7th Floor B-side
PO Box 2-349
Rajdamnern Nok Avenue
Bangkok 10200
Thailand
T: +66 2 2882235
F: +66 2 2881062
E: asist-ap@ilo.org
www.ilo.org/asist & www.iloasist.org

ASIST – Africa
PO Box 210
Harare
Zimbabwe
T: +263 4 369 824-8
F: +263 4 369 829
E: asist@ilo.org
www.ilo.org/asist

Institution of Civil Engineers (ICE)
ICE is an independent engineering institution representing almost 80,000 professionally qualified civil engineers in the UK and worldwide. The objectives of ICE are to promote learning and training, provide professional status, act as a voice of the profession and facilitate best practice. ICE also publishes standard forms of contact, including the NEC series of contracts, suitable for international use.

Great George Street
Westminster
London SW1P 3AA
United Kingdom

T: +44 (0)207 222 7722
F: +44 (0)207 222 7500
www.ice.org.uk

International Forum for Rural Transport and Development (IFRTD)
IFRTD is a global network of individuals and organisations encompassing community organisations, national and international NGOs, academia, governments, donor agencies, consultants and technical institutions. Its mission is to promote policies and practices that address access and mobility as a means to eradicating rural poverty. IRFTD has a decentralised Secretariat based in the UK, Kenya, Peru and Senegal. IFRTD publishes *Forum News* quarterly. The UK address is given above.

113 Spitfire Studios
63-71 Collier Street
London N1 9BE
United Kingdom

T: +44 (0)207 713 6699
F: +44 (0)207 713 8290
E: ifrtd@ifrtd.org
www.ifrtd.org

International Federation of Consulting Engineers (FIDIC)
FIDIC is an international federation of national associations of consulting engineers. FIDIC acts as a forum for the exchange of views and information and actively encourages the discussion of matters of mutual concern among member associations. More information, including order forms for contracts and other publications, is available on the website.

PO Box 311
CH-1215
Geneva 15
Switzerland

T: +41 22 799 49 00
F: +41 22 799 49 01
E: fidic@fidic.org
www.fidic.org

International Road Federation (IRF)
The IRF is a non-governmental, not-for-profit international organization with public sector, private sector and institutional members in approximately 70 countries. Established in 1948 by business and industry leaders, its mission is to encourage and promote the development and maintenance of better and safer roads and road networks. Today the IRF continues to provide the lead in international road infrastructure and management development through its two programme centres listed below.

Geneva Programme Centre
Chemin de Blandonnet 2
CH-1214 Vernier (Geneva)
Switzerland
T: +41 22 306 0260
F: +41 22 306 0270

Washington Program Centre
1010 Massachusetts Avenue NW
Suite 410
Washington DC 20001
USA
T: +1 (202) 371 5544
F: +1 (202) 371 5565
info@irfnet.org
www.irfnet.org

Norwegian Public Roads Administration (NPRA)
NPRA is the national road authority in Norway. It is responsible for national and county roads, totalling approximately 54,000 km and its duties comprise strategic planning of the network and other modes of transport, contracting of construction and maintenance, traffic management, technical standards, registering and inspecting vehicles and licensing drivers. The Office for International Affairs coordinates Institutional Cooperation with a number of European and African countries.
Statens vegvesen

Vegdirektoratet T: +47 22 07 35 00
Postboks 8142 Dep F: +47 22 07 37 68
0033 OSLO E: firmapost@vegvesen.no
Norway www.vegvesen.no

Southern African Bitumen Association (Sabita)
Sabita leads the bituminous products industry's contribution to development in southern Africa. Funded by its members, Sabita's threefold mission is to promote social and economic development through its road provision programmes, educate and train employees within the industry through formally sanctioned schemes and advance best practice to give competitive delivery of bituminous products and costeffective construction and maintenance of roads.

Postnet Suite 56 T: +27 21 531 2718
Private Bag X21 F: +27 21 531 2606
7450 Howard Place E: info@sabita.co.za
South Africa www.sabita.co.za

Southern Africa Transport and Communications Commission (SATCC)
The main function of the SATCC Technical Unit (SATCC-TU) is to provide administrative and technical support to the implementation agencies and monitor compliance by member states of their obligations in terms of the implementation of the SADC Protocol on Transport, Communications and Meteorology.

From January 2004: T: +267 3951 863
SADC, Private Bag F: +267 3972 848
0095 E: registry@sadc.int
SADC House
Gaborone
Botswana

Transportation Research Board (TRB)
TRB is a unit of the National Research Council, a private, nonprofit institution that is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering. TRB's mission is to promote innovation and progress in transportation by stimulating and conducting research, facilitating the dissemination of information, and encouraging the implementation of research results. TRB hosts an annual meeting which attracts a large number of transport professionals from around the world.

Keck Center of the National Academies T: +1 (202) 334 2934
Transportation Research Board F: +1 (202) 334 2003
500 Fifth Street, NW E: TRBSales@nas.edu
Washington DC 20001 (Publications and Sales)
USA www.trb.org

TRL Limited
TRL Limited is one of the largest and most comprehensive international independent research centres working in land transport. The international staff work on projects for a range of clients, including DFID, the World Bank and the African and Asian Development Banks.

Centre for International Development	T: +44 (0)1344 773131
Old Wokingham Road	F: +44 (0)1344 770356
Crowthorne	E: international_enquiries@trl.co.uk
Berkshire RG45 6AU	www.trl.co.uk
United Kingdom	

World Bank
The World Bank finances many rural transport projects in developing countries and coordinates the Rural Travel and Transport Programme and the Road Maintenance Initiative of the Sub-Saharan African Transport Program (SSATP). Its Rural Transport Thematic Group has produced important knowledge products on rural transport. A large amount of material is available at www.worldbank.org/transport/rt_over.htm

1818 H Street N.W.	T: +1 (202) 473-1000
Washington D.C.	F: +1 (202) 477-6391
20433	www.worldbank.org
USA	

World Road Association (PIARC)
PIARC is a non-political and non-commercial association with a main objective of becoming the world leader in providing information on roads and road transport policy and practices within an integrated sustainable transport context. It co-ordinates international technical committees, organises international seminars and publishes documents.

La Grande Arche	T: +33 (1) 47 96 81 21
Paroi nord, niveau 8	F: +33 (1) 49 00 02 02
92055 La Defense	E: piarc@wanadoo.fr
Paris	www.piarc.org
France	