MINISTRY OF FOREIGN AFFAIRS OF DENMARK

DANIDA | INTERNATIONAL DEVELOPMENT COOPERATION

Review of Low-cost Seal Technology Options on Low Volume Roads in Uganda

Final Report

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
DFID	Department for International Development
DSD	Double Surface Dressing
ESA	Equivalent Standard Axle
EOD	Environmentally Optimised Design
EMC	Equilibrium moisture content
GoU	Government of Uganda
LCS	Low-cost Seal
LVR	Low volume road
LVSR	Low volume sealed road
JICA	Japan International Cooperation Agency
MC	Moisture Content
MELTC	Mount Elgon Labour-Based Training Centre
MDD	Maximum dry density
MoWT	Ministry of Works and Transport
MESA	Million Equivalent Standard Axles
NDP	National Development Plan
RTI	Rural Transport Infrastructure
SADC	Southern African Development Community
SD	Surface Dressing
SSD	Single Surface Dressing
ToR	Terms of Reference
TRL	Transport Research Laboratory
UK	United Kingdom
UNRA	Uganda National Roads Authority
URF	Uganda Road Fund
VEF	Vehicle Equivalence Factor

General Map of Uganda

EXECUTIVE SUMMARY

Background

Through the on-going, Danida supported, Rural Transport Infrastructure (RTI) component of the U-Growth Programme, an initiative has been undertaken to develop low-cost seal (LCS) technology in Uganda. LCSs allow wide use to be made of locally available materials and provide a viable, cost-effective and sustainable alternative to natural gravel surfaces with more manageable maintenance requirements. Such seals may also be constructed by small-scale contractors using relatively low-capital, labour based methods and relatively small mechanised plant.

In anticipation of mainstreaming LCS technology, initially under the RTI program (300 km during the 4-year program period 2010-2013) and subsequently under the Government of Uganda's (GoU) National Development Plan (10,000 km in the 5-year period 2010/11-2014/15), training modules were prepared by a consultant, MELTC staff were trained and a number of types of LCSs were constructed in early 2011 as a demonstration project.

Before a final commitment is made regarding the adoption of LCS technology a concrete justification for so doing is required by the Ministry of Works and Transport (MoWT) as a basis for developing a clear policy and strategy for adoption by GoU. To this end, an assessment of the various key aspects of LCS technology as proposed to be applied in Uganda was carried with the outcomes described below.

Institutional Issues

1. ***Training curriculum:*** This covers most of the basics of LCS technology but would benefit from the inclusion of a number of other topics including borrow pit management and life cycle cost analysis of surfacing options as well as more comprehensive treatment of drainage, quality assurance and a better arrangement of cross-cutting issues.

2. ***Institutional capacity:*** Such capacity is a prerequisite for successful implementation of LCS technology and is likely to be adequate in the short term but not in the medium to long term due to capacity constraints in the districts. MELTC should therefore be supported to fulfil an expanded training role in future the scope of which should be determined on the basis of a training needs assessment.

Technical Issues

1. ***Base preparation:*** In order to achieve optimal utilisation of local materials in the construction of the pavement structure on which LCSs will be applied, the compactive effort employed should be higher than that currently specified in the guidelines.

2. ***LCS trials – performance, options and viability:*** One year after construction, the LCSs trialled are generally performing satisfactorily although some of them appear to be slightly lean on binder application which might impair their performance in the long term The options trialled are common to the region but would have benefitted from two additional, commonly used LCS types – an Otta seal using screened gravel and a Cape seal. These

LCSs are viable to varying extents in the context of relatively small-scale works undertaken by relatively small-scale contractors providing modest levels of productivity.

3. ***Availability of materials and plant for LCS options and adaptability to labour-based technology:*** All the materials and plant required for the construction of the LCSs are available but at haul distances that would vary from district to district. For adaptability to labour-based technology, there would naturally be a preference for hand-knapped or screened rather than machine crushed aggregate; for cold applied (emulsion) rather than hot applied (cut-back) binders and for relatively small and inexpensive mechanised plant (e.g. concrete mixers, hand-lance sprayers) rather than more expensive mechanised plant (e.g. bitumen distributors with heating devices) which may not be readily obtainable by small contractors.

Economic and Financial Issues

1. ***Cost-effectiveness*:** Based on a life-cycle cost analysis, the most cost-effective seals are the graded aggregate Otta seals and the least cost-effective include Penetration Macadam, inverted surface dressing and cold mix asphalt.

2. ***Maintenance funding requirements and sources:*** In order to preserve the investments made in the construction of LCSs a reliable and sustainable source of funding for maintenance will be required. The Uganda Road Fund (URF) currently confines the use of its allocations to the districts for gravel road maintenance only. However, in view of the better value for money offered by LCS technology, the URF would be open to amending its legislation to allow such funding to be used for LCS works contingent upon receipt of a well documented proposal which justifies the economic viability of LCS technology.

Contractual and implementation issues

1. ***Selection of LCS options:*** This is very project specific and dependent on a wide array of factors including plant or materials availability, site conditions and local maintenance capability.

2. ***Preferences of MoWT pertaining to choice of LCS type:*** Such preferences would entail consideration of such factors as:

   a. *Institutional arrangements*: In-house or outsourcing of design and supervision of LCS works in relation to capacity dictates.

   b. *Labour-based versus equipment based technology:* In relation to the application of LCS technology on low-trafficked (mostly district) or high-trafficked (mostly national) road.

   c. *Choice of surfacing type:* In relation to application of LCS technology n a relatively low-trafficked rural environment or relatively high-trafficked urban environment.

3. ***Approach for implementation of trial contracts:*** The expectation that the LCS technology would be applied on road sections in connection with other rehabilitation works has not been realised in practice and a certain amount of preparatory pre-sealing works will be required prior to the application of the LCSs. Based on a budget of UGX 1.25 billion for the trial contracts, and on an average construction costs of UGX 100 million/km for the most cost-effective LCSs likely to be implemented in practice, the total kilometrage likely to be achieved is of the order of 10 km in contrast to the 34.5 km originally envisaged. If the cost of the pre-sealing contracts is included, resulting in a total construction cost of UGX 180 million/km, then the kilometrage likely to be achieved will be further reduced to just 7.0 km. Thus, in either scenario considered, it will not be possible to undertake the trialling of at least three LCS options with a minimum practicable length of 300 m in each of the 23 districts. Instead, as a compromise, it may be necessary to allow all 25 contractors to undertake the construction of one LCS type of 500 m length in each district (budget used for LCS works only) or one LCS type of 280 m (budget used for pre-sealing works plus LCS works). The merit in allowing each of the 25 contractors to participate in the trial contracts is to sustain their interest in LCS works for the future.

4. ***Revised target for LCS programme:*** The original 2009 budget of UGX 15 billion that was earmarked for construction of 300 km of LCS roads in the RTI program has been eroded by an average of 17% inflation over a 3 year period to a current figure of UGX 9.5 billion. This budget will allow a total RTI program of 76 km of LCS works, based on the current cost of LCS construction and preparatory works of UGX 125 million/km. Assuming that the delayed RTI program can commence in April 2013, then the reduced 75 km target should easily be achievable by small-scale contractors.

5. ***Assumptions and risks for LCS implementation under RTI***. There are a number of assumptions and risks associated with LCS implementation under RTI that need to be addressed by the adoption of a number of mitigation measures including development of realistic budgets for implementing LCS technology under GoU's NDP, preparing a project document highlighting the viability of LCS technology to facilitate the inclusion of LCS policy in the NDP and to convince the URF of the value for money benefits of using maintenance funds for the upkeep of LCS roads.

6. ***Promotion and implementation of LCS technology:*** A number of important links in the pathway from research to implementation which are critical to the attainment of sustainable LCS implementation still need to be addressed including the production of a Manual on Materials and Pavement Design for low volume sealed roads, the holding of workshops and seminars on LCS technology and the production of the documentation required for uptake by GoU.

1. INTRODUCTION

1.1 Background

Roads provide the dominant mode of transport in Uganda and play a vital role in the socio-economic growth and development of the country. Improving road infrastructure has therefore received high priority in the National Development Plan (NDP) of the Government of Uganda (GoU). To this end, the Danish Government is providing support to Component 2 of the GoU's four-year U-Growth Programme (2010-2013): *Rural Transport Infrastructure (RTI) Support for Agricultural Development.*

The objective of the RTI component of the U-Growth Programme is "*to develop and maintain district, urban and community access roads to promote cheaper, efficient and reliable transport services to facilitate access to markets for rural agricultural produce, promote extension services and access to agricultural inputs by rural farmers, and improve access to social services."* This component is a continuation of the labour-based methodologies from the previous programmes which offer job opportunities for persons from poor rural households. It also creates business opportunities for local labour-based trained contractors and thus contributes to the local economic growth.

An important goal of the RTI is to develop a number of different types of *low-cost surfacings* (LCS) for use on unsealed low volume roads in Uganda. Such surfacings can provide a viable, cost effective, alternative to unsealed roads which require the use of a non-renewable resource (gravel) that is being seriously depleted in the country and, in the process, is also causing serious environmental problems. Sealed roads also offer lower transport costs and more manageable maintenance requirements than gravel roads.

In anticipation of the eventual mainstreaming of the LCS technology, one of the subcomponents of the RTI is to construct 300 km of low-cost sealed district roads. In addition, in their current NDP, the GoU has plans to adopt the LCS technology to improve up to 10,000 km of district roads in five years (2010/11–2014/15). However, before doing so, a clear policy and strategy needs to be developed by the Ministry of Works and Transport (MoWT). Such a strategy needs to be informed by hard evidence from the trials carried out in Uganda that the LCS approach is, in fact, a viable and sustainable option for surfacing of roads in the country.

1.2 Objectives

Despite the proven benefits of LCS technology experienced by countries in the region, relatively limited research has been undertaken in Uganda to quantify the benefits of introducing this new technology to the country. As a result, a consultancy has been let with the overall objective of providing concrete justification for the application of this technology which, if it is to be successfully implemented, must be appropriate for the local conditions prevailing in the districts under the current RTI support. The outputs of the consultancy are also expected to provide an important input to the development of the MoWT policy and strategy on the LCS technology.

1.3 Scope of Work

The scope of work required to be undertaken to achieve the overall objectives of the consultancy as outlined above are elaborated upon in the Terms of Reference (Annex A) and may be summarised as follows:

- An assessment of the various proposed LCS options.
- Cost-benefit analysis of the different options (based on a life-cycle cost analysis).
- An assessment of the availability of equipment and materials.
- Adaptability of the various options to labour-based technology.
- Maintenance needs and methodologies.
- Wider sustainability issues including financial implications and government commitment.
- An estimate of realistic targets for LCS achievement by the end of the RTI programme.

1.4 General Approach

The general approach adopted for undertaking the consultancy, which was carried out between 6th August and 7th September 2012, may be summarised as follows:

- Review of relevant documents including training modules in low-cost sealing of roads in Uganda that were prepared by the UK Transport Research Laboratory for MELTC;
- Briefing meetings with the Danish Embassy and MoWT;
- Consultations with various government stakeholders including: MoWT (Construction Standards and Quality Management), Mount Elgon Labour-based Training Centre (MELTC), the Uganda National Roads Authority (UNRA) and the Uganda Road Fund;
- Consultations with development partners including: DFID, JICA;
- Consultations with local consultants and contractors involved previously in LCS works;
- Field visits to the LCS demonstration site at Mbale and to selected districts earmarked for implementing LCS projects (Kumi, Lira and Gulu).
- Field visit to the Matugga-Semuto-Kapeeke Road Trial where various LCSs were trialled.

A list of the various stakeholders consulted during the Consultants' visit to Uganda is presented in Annex B.

1.5 Structure of Report

This report is structured as follows:

Section 1 (this section): provides the background context, objectives, scope of work and general approach followed in carrying out the review of LCS technology in Uganda.

Section 2: Presents an overview of LCS technology in order to provide the necessary background to facilitate the assessment of the various key issues raised in the terms of Reference.

Section 3: Provides a detailed assessment of all the institutional, technical, economic & financial and contractual & implementation issues pertaining to LCS technology in Uganda.

Section 4: Summarises the conclusions and recommendations arising from the review of LCS technology options in Uganda.

2. OVERVIEW OF LCS TECHNOLOGY

2.1 Introduction

A common understanding of the basic elements of LCS technology, and how it has so far developed in Uganda, is required to provide the necessary background to facilitate the assessment of the various key issues raised in the Terms of Reference. This section therefore considers a number of aspects of LCS technology and the factors affecting its implementation in the country.

2.2 LCS Technology and Environmentally Optimised Design

In order to obtain optimal results from investments in road infrastructure in any country, it is important to adopt an approach that is guided by appropriate local standards and conditions, in order to achieve a sustainable outcome. In this regard, international and regional research has highlighted the benefits of applying the principles of Environmentally Optimised Design (EOD) to the design and construction of low volume rural roads (Cook et al, 2008). The various factors that influence the implementation of LCS technology and that need to be considered in the context of EOD are illustrated in Figure 2-1.

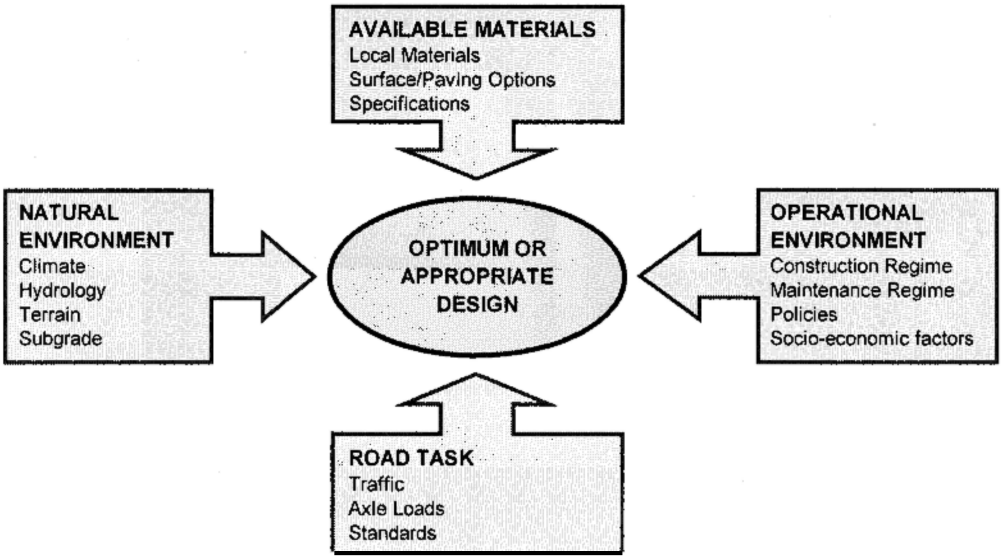


Figure 2-1: LCS implementation within an EOD context

In essence, EOD can be described as a strategy for utilising the available resources of budget and materials in the most cost-effective manner to counter the variable factors of traffic, terrain, materials and subgrade that may exist along an alignment. To be successful and sustainable, LCS technology needs to be implemented within the framework of an EOD strategy. Moreover, if the LCS project is to be sustainable in the long run a number of strategic objectives should be satisfied, including:

- Maximum use of local labour and skills
- Maximum use of locally available or produced materials
- Use of appropriate design standards and materials specifications
- Low capital investment (relatively simple equipment requirements)
- Socially and environmentally acceptable use of materials and construction practices

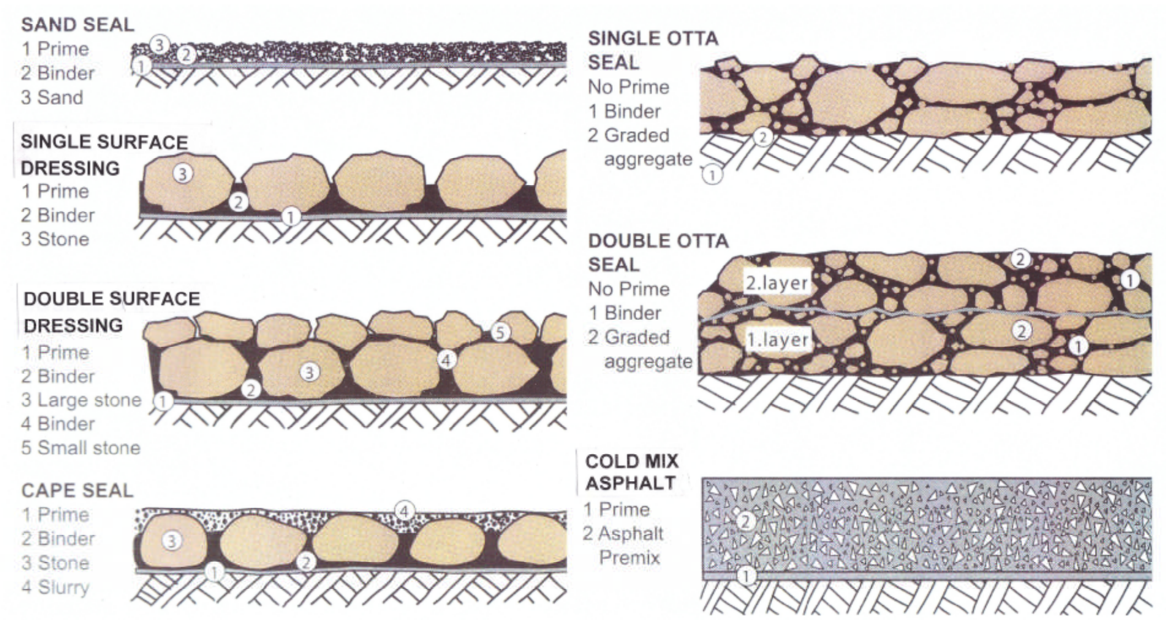
It is worth emphasising that EOD applies to the appropriate design of **both the surfacing and pavement structure of a low volume road**. Thus, in order to derive the full benefits of an EOD approach, **LCS technology must be applied in conjunction with a low volume sealed road (LVSR) design strategy** (SADC, 2003). This strategy is based on the use of appropriate, performance-related, standards and specifications derived from research carried out in the region in preference to the more traditional standards and specifications that are more appropriate for application to high volume roads.

2.3 Types and Characteristics of Low-cost Seals

2.3.1 General

A basic appreciation of the characteristics of the different types of low-cost seals constructed at Mbale is required so as to facilitate an understanding of the subsequent assessment of the many issues related to the adoption LCS technology in Uganda. Such information for typical types of LCSs is provided in Figure 2-1 and is described further below.

Figure 2-2: Common types of low-cost surfacings



Notes:
1. Penetration Macadam and inverted surface dressing not shown
2. Cape Seal not constructed at Mbale
3. Single chip seal + sand seal similar to cape Seal but with slurry replaced by sand

2.3.2 Characteristics of Low-Cost Seals

Table 2-1 provides an overview of the characteristics of different types of low-cost seals.

Table 2-1: Characteristics of low-cost seals

LCS	Characteristics
Sand seal	- Empirical design. - Consists of a prime coat, a film of binder (cutback bitumen or emulsion) followed by a graded natural sand or fine sand-sized machine or hand-broken aggregate (max. size typically 6 – 7 mm) which must then be compacted. - Is primarily a temporary surfacing, or for application on top of other seals. - Especially useful if good aggregate is hard to find. - Very suitable for labour-based construction, especially where emulsions are used, and requires simple construction plant. - Single sand seals are not very durable (life of 3-4 years) but performance can be improved with the application of a second seal (life of 6-7 years).
Slurry seal	- Empirical design. - Consists of a mixture of fine aggregates, Portland cement, emulsion binder and additional water to produce a thick creamy consistency which is spread to a thickness of 5-15 mm. - Not normally used on new roads; more typically used for re-texturing surface dressings prior to resealing or for constructing Cape seals. - Very suitable for labour-based construction using relatively simple construction plant (concrete mixer) to mix the slurry. - Thin slurry (5 mm) is not very durable (life 3-4 years) but performance can be improved with the application of a thicker (15 mm) slurry (life span of 6-7 years).
Surface dressing	- Rational design. - Consists of a binder (emulsion or penetration grade) sprayed onto the previously primed surface and then covered with a layer of crushed aggregate chippings (single surface dressing – SSD) or with a second another application of binder and aggregate (double surface dressing – DSD). - DSD usually used to seal an unpaved surface; SSD used as a maintenance treatment for existing bituminous sealed roads or in combination with a sand seal to improve its durability. - Fairly suitable for labour-based construction and, when emulsion is used, requires relatively simple construction plant. - SSD+ sand seal is fairly durable (life 6-7 years) but performance can be improved with the application of a second seal (life span of 8-10 years).
Otta seal	- Empirical design. - Consists of a low viscosity binder (e.g. cutback bitumen, MC 3000 or 150/200 penetration grade bitumen) followed by a layer of graded aggregate (crushed or screened) with a maximum size of up to 19 mm. - Due to the fines in the aggregate, requires extensive rolling to ensure that the binder is flushed to the surface. - May be constructed in a single layer or, for improved durability, with a sand seal over a single layer or in a double layer. - Very suitable for labour-based construction but requires relatively complex construction plant (bitumen distributor + binder heating facilities). - Provides a very durable type of surfacing (life span of 5-6 years for single seal, 8-10 years for single seal + sand seal and 12-15 years for double seal).

Cape Seal	- Partly rational (surface dressing) and partly empirical (slurry seal) design. - Consists of a single 19 mm or 13 mm surface dressing followed by two layers or one layer respectively of slurry. The primary purpose of the slurry is to fill the voids between the chips to produce a tightly bound, dense surfacing. - Fairly suitable for labour-based construction and, when emulsion is used with the surface dressing; can be constructed with relatively simple plant. - Produces a very durable surfacing, particularly with the 19 mm aggregate + two slurry applications (life span of 12 – 15 years).
Penetration macadam	- Empirical design - Constructed by first applying a layer of rolled coarse (e.g. 40/60 mm aggregate) followed by the application of emulsion or penetration grade binder. Next, the surface voids in the coarse aggregate layer are filled with finer aggregate (e.g. 10/20 mm aggregate) to lock in the coarse aggregate followed by an additional application of emulsion binder which is then covered with fine aggregate (e.g. 5/10 mm) and rolled. - Very suitable for labour-based construction as aggregate and emulsion can be laid by hand. - Produces a stable interlocking, robust layer after compaction (life of 8-10 years) but the cost is relatively high due to the high rate of application of bitumen.
Cold mix asphalt	- Empirical design - Consists of an admixture of graded gravel (similar to an Otta seal) and a stable, slow-breaking emulsion which is mixed by hand or in a concrete mixer. After mixing the material is spread on a primed road base and rolled. 1.3.1 Very suitable for labour-based construction; requires very simple construction plant. - Produces a dense surfacing, comparable to an Otta seal (life span of 8-10 years)

3. ASSESSMENT OF KEY LCS ISSUES

3.1 Introduction

This section provides the outcome of the assessment made of all the key issues listed in the Terms of Reference which are all aimed at providing a justification of the viability or otherwise of the LCS technology in the Ugandan environment. These issues are addressed under the following headings:

- Institutional issues.
- Technical issues.
- Economic and financial issues.
- Contractual and implementation issues.

3.2 Institutional Issues

3.2.1 Training in LCS technology at MELTC

Scope of training

In anticipation of the expected implementation of LCS technology in Uganda, the Ministry of Works and Transport in October 2010 engaged a consultant (the UK Transport Research Laboratory (TRL)) to prepare training modules, to train MELTC personnel in labour-based low-cost sealing (classroom and on-site demonstrations) and to prepare guidelines and specifications for use of locally available materials on low-volume traffic roads including developing quality control measures for the low-cost sealing of roads.

The training of MELTC staff in LCS technology was carried out over the period October 2010 to August 2011 and comprised both classroom activities, covered in seven modules (see TRL report, as well as field activities, as listed in Table 3-1 and documented in the TRL reports.

Table 3-1: Scope of training carried out by TRL at MELTC

Module No.	Module Description	Classroom (days)	Field (days)
1	***Road evaluation***: Assessing candidate roads, selection, and conducting technical surveys, and laboratory testing.	1	2
2	***Road improvement:*** selecting base material, manipulating materials, designing and constructing roads to receive a surfacing.	1	2
3	***Design of surfacings***: selection of materials, choice and design of various surfacings.	1	0
4	***Occupational health, safety and environmental issues***: issues to consider from OSHE standpoint, governing Acts, Risks and Personal Protective Equipment.	1	1
5	***Preparation for surfacing works***: Planning for surfacing, organising the site, personnel, equipment and tools.	1	2
6	***Surfacing operations:*** work methods for construction of different surfacings using labour-based techniques.	1	6
7	***Maintenance of surfacings***: Planning for maintenance, understanding defects and application of remedial treatments.	1	1

As part of the field training activities, practical demonstrations of the construction of the following types of low-cost seals were undertaken on a 0.6 km trial section of the Busamaga-Magada-Bumulya road in Mbale:

1. Single sand seal (river sand)
2. Single sand seal (quarry sand)
3. Single surface dressing
4. Single surface dressing + sand seal (river sand)
5. Single surface dressing + sand seal (quarry sand)
6. Single Otta seal
7. Cold mix asphalt (premix)
8. Penetration macadam

Proposed training curriculum

It is assumed that the proposed training curriculum to be followed in future at MELTC will be based on the seven training modules prepared by TRL for the organisation. This curriculum covers the fundamentals of LCS technology in terms of equipping trainees with a basic understanding of the planning, design, construction and maintenance requirements of low volume roads using labour-based methods and adopting so-called “low-cost” seal technology.

In terms of the adequacy of the current curriculum for future national needs of the country, the following suggestions are offered in the context of the substantial LCS programme envisaged by GoU in their NDP:

(a) Additions to current scope of curriculum

The following topics are considered sufficiently important to the successful implementation of LCS technology to warrant inclusion in an expanded training curriculum:

(i) **Borrow pit management** including such issues as:

a. Borrow pit site investigation
b. Pit quarry evaluation, selection and preparation
c. Pit preparation
d. Material extraction, processing and control
e. Environmental considerations

(ii) **Road safety** including such topics as:

a. Speed reduction measures in villages considering
    i. The approach zone, transition zone and core zone

(iii) **Cost analysis of surfacing options** including such topics as:

a. Life cycle cost analysis
b. Surfacing selection framework

(b) Enhancements to current scope of curriculum

Based on discussions with stakeholders, the following recommendations are made:

(i) Improved organisation of **cross-cutting issues**, including:

a. Separation of health issues from worker safety
b. Categorisation of accident sources
c. Stand-alone section on environmental impacts
d. Specific consideration of issues as:
   i. Gender and women's participation in labour-based road works
   ii. Human rights, good governance, labour and workplace safety
   iii. Health issues, including HIV/AIDS
   iv. Community participation in road works activities

(ii) Expanded treatment of drainage requirements, including:

a. Surface and sub-surface drainage
b. Drainage channels (types of side drains, erosion control devices) and culverts.

3.2.2 Institutional capacity

Adequate capacity at all levels of government (national, regional and local) and within the private sector (consultants, contractors and materials suppliers) is an essential pre-requisite for the successful implementation of LCS technology in Uganda. Without such capacity, the LCS technology is hardly likely to be sustainable in the long term. To this end, such capacity is assessed as follows:

MELTC has been the recipient of intensive training in both the theoretical and practical aspects of LCS technology and has been provided with training materials which provide a valuable resource for institutionalising such technology in Uganda. To date, MELTC has played a key role in disseminating LCS technology by providing training to district technical staff and contractors in 23 districts in the North of Uganda.

The LCS technology dissemination and mentorship role played so far by MELTC should suffice for the implementation of the envisaged 38 km of trial contracts in 23 districts for which the designs and tendering are being undertaken by district technical staff. However, beyond that horizon is the anticipated target of some 300 km of district sealed with LCS during the four year programme period (2010-2013) and, in the longer term, GOU's planned implementation of 10,000 km of district roads using LCS technology. Achievement of these latter targets, coupled with UNRA's interest in applying LCS technology on national roads, will be frustrated unless a clearly enunciated training strategy is put in place to satisfy this demand in both the public (Urban and District Councils) and private (consultants) sectors.

MELTC is well placed to expand its current training programme to meet the anticipated demand as described above. However, this will require that a training needs assessment is carried out to quantify that demand and that funding be provided to allow the organisation to re-organise itself to fulfil its critical training and capacity building role that is so necessary to ensure the long term sustainability of LCS technology in Uganda.

3.3 Technical Issues

3.3.1 Base preparation

In order for a labour-based constructed low volume sealed road to perform well, it is absolutely critical that the running surface of the existing gravel road (typically the subbase of the upgraded road) and any imported layers are compacted to the maximum dry density practicable, i.e. without incurring breakdown of the material. In so doing, there will be beneficial gain in strength and stiffness and reduction in permeability of the pavement layers resulting in stronger layer support, lesser thickness of the overlying layer(s) and, generally, a more economic pavement structure based on life cycle costs.

In light of the above, it is significant that the specified density stipulated for the base preparation of the trials sections was only 95% Standard (light) AASHTO compaction and, moreover, because of the light (1.7 tonne pedestrian) roller used the base layer had to be constructed in two 75 mm layers. In view of the overall economic benefits to be gained from a higher compactive effort, it is recommended that, where practicable, the compaction requirement of the base and subbase layers should be specified as a minimum of 95% and 98% Modified (heavy) AASHTO compaction respectively. This can be achieved with a 5 tonne towed vibratory roller. Because of the sensitivity to density of many of the local materials, such as laterite, the strength achieved by compacting to a higher density will increase the overall utilisation of local materials in the construction of the roads.

3.3.2 LCSs trials and early performance

Details of the eight types of LCS options under demonstration on the Busamaga-Magada-Bumulya road are well documented in the TRL training report "Site Establishment and Execution of Works, June 2011", and are summarised in Table 3-2.

Table 3-2: Details of LCS options trialled on demonstration project:

Chainage	Surfacing Type	Aggregate used	Bitumen used
S1: 0+00 to 0+100	Penetration Macadam	Hand crushed	K1-60 Emulsion (80/100 pen. Grade)
S2: 0+100 to 0+150	SSD + river sand seal	Machine crushed	K1-60 Emulsion (80/100 pen. Grade)
S3: 0+150 to 0+200	SSD + quarry sand seal	Machine crushed	K1-60 Emulsion (80/100 pen. Grade)
S4: 0+200 to 0+300	Quarry sand seal	Quarry sand	K1-60 Emulsion (80/100 pen. Grade)
S5: 0+300 to 0+400	SSD (control)	Machine crushed	K1-60 Emulsion (80/100 pen. Grade)
S6: 0+400 to 0+500	Sand seal	River sand	K1-60 Emulsion (80/100 pen. Grade)
S7: 0+500 to 0+580	Otta seal	Hand crushed	K1-60 Emulsion (80/100 pen. Grade)
S8: 0+580 to 0+600	Cold mix asphalt	Hand crushed	K1-60 Emulsion (80/100 pen. Grade)

At the time of inspection of the LCS trial sections in August 2012, they were just over one year in service which is a relatively short time for any defects to show up, unless there was a major problem with the design or construction of the surfacing, which was not the case.

In general, most of the seals appear to be performing satisfactorily. However, during the walk-over inspection with the MELTC team, the following observations were noted for subsequent monitoring and fine tuning of the designs, where appropriate.

(1) Section1 – Penetration Macadam: 20-37.5mm & 5-13mm chippings

The surfacing appears rather open with apparent segregation of the 20-40 mm layer. The second layer of chippings also appears very open and bitumen deficient.

(2) Section 2 – Single surface dressing: 10-14 mm chippings +quarry sand seal <5 mm

The surfacing appears good with sufficient binder application; the sand seal has been almost completely lost, probably due to insufficient binder application.

1.3.2 Section 3- Single Surface dressing: 10-14 mm chippings + river sand seal <5 mm

The surfacing looks good, but some loss of the sand seal, probably due to insufficient binder application.

.

(4) Section 4- Single sand seal: <5 mm river sand

The surfacing appears bitumen deficient; the spray rate could probably have been increased by the order 0,2 -0,3 l/m^2.

(5) Section 5 –Single surface dressing: 10-14 mm chippings

The surfacing appears bitumen deficient; the spray rate could probably have been increased by the order of 0,2 -0,3 l/m^2.

(6) Section 6 – Sand seal: <5 mm quarry sand

The surfacing appears bitumen deficient; the spray rate could probably have been increased by the order of 0,2 -0,3 l/m^2

(7) Section 7 – Single Otta seal: < 13 mm crushed aggregate

The surfacing appears fairly dense and contains about 10-15% oversize larger that 13 mm with . some of the aggregate being larger that 19 mm; ; the spray rate could probably have been increased by the order of 0,2 -0,3 l/m^2

(8) Section 8. Cold Mix Asphalt (Premix): <13 mm crushed aggregate

The surfacing appears somewhat bitumen deficient; the spray rate could probably have been increased by the order of 0,2 -0,3 l/m^2

In summary, some of the seals appear be lean looking, i.e. to suffer from an under application of binder. This has resulted in significant loss of the sand capping seal in Sections 2 and 3 which is likely to reduce their durability in service and to require resealing sooner than might have otherwise been the case, had the sand seal not been largely lost soon after construction.

It was also observed that where the hand spraying lance was used transversely to apply emulsion or MC30, it tended to produce an overlap of excess bitumen which, after the spreading of aggregate, tended to create a series of transverse ridges. To avoid this common defect, the spray lance should be used preferably in the longitudinal direction as the longitudinal ridges are less noticeable to traffic.

3.3.3 Choice of LCSs options

The range of LCS options trialled on the demonstration project are largely typical of those often used in the region. However, there are two additional options that have been used in a number of countries and are likely to be viable in the Ugandan environment and could be considered in future. These are:

(a) Otta seal using screened gravel rather than crushed aggregate. Naturally occurring gravel is often generally available from laterite or quartzitic borrow pits and, when screened to the appropriate range of sizes, can be utilised often at lower cost than crushed aggregate or, indeed, utilised where crushed aggregate is not readily available. The use of a coarse grading (0-19 mm) would produce a more durable seal than a finer grading (0-13 mm).

Screened quartzitic gravel has been used successfully in a number of countries including Botswana, Ghana, Kenya, Tanzania and South Africa. Similarly, screened laterite has been used successfully in Botswana, Kenya and Tanzania.

(b) Cape seal: This consists of a 13.2 mm or 19 mm surface dressing using a 80/100 or 150/200 pen. grade binder or emulsion followed by one or two layers of slurry as appropriate for the nominal maximum aggregate size selected. A diluted emulsion spray is normally applied before the application of the slurry.

This type of seal is one of the more durable options, similar to a double Otta seal, but is more suited to labour-based construction than the latter as it can be constructed with a cold applied emulsion binder rather than a hot applied penetration grade binder.

3.3.4 Viability of LCS options

To varying extents, all the seals that have been demonstrated on the Busamaga-Magada-Bumulya road in Mbale are viable, in that it is feasible and practicable to construct them but with the qualification that such viability is in the context of <u>relatively small-scale projects undertaken by small-scale contractors providing modest levels of productivity.</u> The implementation of these same LCS options on a larger scale, using larger contractors and expected higher levels of productivity would require quite different labour, plant and materials requirements and construction strategies.

In assessing the overall viability of LCS options, a number of key factors, such as suitability for construction by labour based methods, suitability and availability of materials, etc., issues which are discussed under various headings below.

3.3.5 Availability and suitability of materials and plant for LCS options

(a) Aggregates

The use of some type of aggregate is required for the construction of all types of LCSs. Such aggregate is generally available in all districts and may be produced by three methods as illustrated in the photographs below, viz:

(1) Crushed aggregate from a crusher in a quarry (equipment intensive).
(2) Hand-knapped aggregate from a quarry (labour intensive).
(3) Screened gravel from a borrow pit (labour-intensive).

(1) Crushed aggregate **(2) Hand-knapped aggregate** **(3) Screened gravel**

The characteristics of the aggregate in terms primarily of their shape (rounded, angular) and manner of production (equipment, labour) dictate their suitability for use with the various types of LCSs as summarised in Table 3-3.

Table 3-3: Aggregate requirements for LCSs

Surfacing type	Aggregate shape		Manner of aggregate production		
	Angular	Rounded	Crusher	Hand-knapped	Screened[1]
Sand seal	✓	✓	✓	✓	✓
Slurry seal	✓	✓	✓	✓	✓
Surface dressing	✓	✗	✓	✓[2]	✗
Otta seal	✓[3]	✓[3]	✓	✓	✓
Cape seal	✓	✗	✓	✓[2]	✗
Cold mix asphalt	✓	✓	✓	✓	✓
Pen. Macadam	✓	✗	✓	✓	✗

1 – Applies to natural gravel obtained from a borrow pit
2 – Need for careful control to avoid producing flaky aggregate
3 – Can tolerate much lower aggregate crushing strength without impairment to the performance of the seal.

(b) Bituminous binders

All the LCSs described above require the use of bituminous binders during construction as indicated in Table 3-4. Depending on the particular LCS or the availability of binder, they may be emulsions that are applied cold or cut-back binders that require heating to a specific temperature.

Table 3-4: Bituminous binder requirements for LCSs

Surfacing type	Type of bituminous binder	
	Emulsion	Cut-back[1]
Sand seal	✓	✓
Slurry seal	✓	✗
Surface dressing	✓	✓
Otta seal	✗	✓
Cape seal	✓	✓
Cold mix asphalt	✓	✗
Pen. Macadam	✓	✓

1 – A safe method of heating is essential

The type of bitumen used affects its suitability for labour-based construction. Bitumen emulsions obviously lend themselves best to labour-based methods rather than bitumens that need to be heated prior to application. Emulsions can be used at ambient temperature with hand lances and therefore present few hazards to the workforce. In contrast, the use of hot bitumen can present potential hazards for the labour force. However, with protective clothing and good procedures, safety can be assured.

(c) Plant and equipment

The essential activities associated with the construction of all types of LCSs include:

- Applying the prime and binder.
- Spreading the aggregate.
- Rolling the aggregate.

The type of plant required for carrying out the above activities is related to the type of seal, with some seal types requiring small mechanised plant (e.g. concrete mixer, pedestrian roller, motor powered pump and hand-lance sprayer) whilst other seal types require larger mechanised plant (e.g. bitumen distributor) for achieving a satisfactory result (see Table 3-5 and photos below). Obviously, the simpler the type of plant required to construct a LCS, the better suited it is for labour-based works.

Table 3-5: Plant requirements for LCSs

Surfacing type	Type of mechanised plant	
	Small	Large
Sand seal	✓	✓
Slurry seal	✓	✓
Surface dressing	✓	✓
Otta seal	✗	✓
Cape seal	✓	✓
Cold mix asphalt	✓	✓
Pen. Macadam	✓	✓

(a) Motor powered pump and hand lance sprayer

(b) Bitumen distributor with heating device

3.3.6 Adaptability of LCS options for labour-based technology

The adaptability of the LCS options for labour-based technology is dictated by the ease and simplicity with which labour can be used to construct the works in terms of the input requirements of materials (aggregate and binder) and plant. For example, the seal option most adaptable for labour-based construction would be one that uses hand-knapped or screened rather than machine crushed aggregate, cold rather than hot applied binder and "simple" rather than "complex" construction plant. On that basis, the adaptability of the various LCS options that may be considered for use in Uganda is summarised in Table 3-6.
Consideration should also be given to constructing a towed pneumatic roller which would be well suited to providing the kneading action required to bind the aggregate and binder more effectively than a steel wheel roller, which also tends to breakdown the weaker chippings.

Table 3-6: Adaptability of the LCS options for labour-based technology

Surfacing type	LCS construction inputs			
	Aggregate	Binder	Plant	Overall
Sand seal	High (hand-knapped)	High (cold)	High (simple)	High
Slurry seal	High (hand-knapped)	High (cold)	High (simple)	High
Surface dressing	Low (machine crushed)	High (cold)	High (simple)	Medium
Otta seal	High (hand-knapped)	Low (hot)	Low (complex)	Low
Cape seal	Low (machine crushed)	High (cold)	High (simple)	Medium
Cold mix asphalt	High (hand-knapped)	High (cold)	High (simple)	High
Pen. Macadam	High (hand-knapped)	High (cold)	High (simple)	High

Of course, the adaptability of the LCS options to labour-based technology is not the only criterion for selecting the type of seal. A number of other criteria, such as cost-effectiveness, maintenance capability, site conditions (e.g. gradient, turning actions) are also just as important, as discussed in Section 3.5.1.

Common practice is not to use sprayed seals on longitudinal gradients in excess of 12%. Where emulsion or cutback binders are used, the gradient should not exceed about 6%.

3.3.7 Adaptability of LCS options for a mix of labour-based and equipment-based methods of construction

The mix of labour and highly mechanized equipment can only improve the quality of the workmanship in comparison with only labour-based methods. For example, the spraying of the required application rate of binder will be more uniform compared with hand spraying. Also, the use of self-propelled pneumatic rollers will embed (knead) the aggregate more effectively and quickly compared with the use of lighter pedestrian rollers employed with labour-based methods.

The extraction and screening of the aggregate by labour do not reduce the quality of the aggregate, whilst the transport of the aggregate to site is more a matter of capacity and organsation, rather than whether machine or labour based operations are used.

The preparatory work prior to the sealing operations such as cleaning/brooming the base and watering prior to applying the prime or binder for the surfacing have no limitations in the use of labour if carefully planned in comparison to the use of mechanical broom and water bowsers.

The use of labour for priming purposes can also be used but the application rate will not be as uniform and consistent as compared wit the use of a self-propelled bitumen distributor

The application of the aggregate by labour can be as effective as for the use of a tail mounted chip spreader or a self-propelled chip spreader. However, such an operation must be well organized by employing a sufficient number of labourers and by pre-stockpiling the aggregate in small heaps at appropriate intervals along the road to be surfaced. For a sand seal and Otta seal surfacing, a dragbroom pulled by labourers will even out irregularities in the aggregate application applied by labourers.

3.3.8 Maintenance needs and methodologies

All LCSs will require some form of routine, recurrent and periodic maintenance after construction, the type and extent of which would depend primarily on the durability of the surfacing which, in turn, would be affected by factors such as:

- Quality of pavement construction and seal design.
- Quality (durability) of the binder
- Environment (climate – rainfall and solar radiation).
- Road alignment (gradient, intersections).
- Traffic (volume and composition).

Each surfacing type has a different resistance to the factors listed above. In general, relatively thin surfacings, such as sand and slurry seals, tend by their make-up to be less durable than the thicker, more robust, surfacings, such as double surface dressings, Otta seals, Cape Seals and Penetration Macadam, cold mix asphalt.

The maintenance needs of the different types of LCSs are manifested in the form of different types of surfacing defects. These defects are, to some extent, influenced by the type of seal, as summarised in Table 3-7:

Table 3-7: Description and causes of typical LCS defects

Surface defect	Description and causes of occurrence
Potholes	Develop from cracks caused by traffic action or extreme loss of aggregate followed by ingress of water into the pavement layers.
Cracking	Caused by a variety of factors including settlement of embankments (longitudinal and transverse), shrinkage of stabilised pavement layers (block), traffic action causing fatigue (crocodile), shrinkage of bituminous surfacing as binder ages (surface).
Ravelling	Caused by loss of surfacing aggregate usually due to abrasive action of traffic and/or insufficient binder and/or the wrong grade of binder.
Bleeding	Caused by excess of binder on the surface due to over-application of binder or embedment of aggregate.
Edge break	Breaking away of surfacing at the edges of the pavement caused by poor shoulder maintenance.

The activities required to deal with the above types of surfacing defects include:

- Recurrent maintenance
  - Pothole repairs.
  - Surface patching.
  - Crack sealing.
  - Edge repairs.
- Periodic maintenance
  - Rejuvenation seal (fog spray).
  - Resealing.

The susceptibility of the various types of LCSs to the various maintenance related issues discussed above may be assessed in terms of such factors as environmental risk, maintenance capability requirement and road gradient as summarised in Table 3-8:

Table 3-8: Susceptibility of LCSs to environment, maintenance sensitivity and gradient

Type of surfacing	Environmental risk	Sensitivity to maintenance	Applicable gradient limit	
			Mild/Flat	Severe/Steep
Single sand seal	High	Low	Fair	Poor
Double sand seal	Medium	Low	Fair	Poor
Single SD	High	Low	Good	Fair
Single SD + sand	Medium	Medium	Good	Fair
Double SD	Low	Medium	Good	Good
Otta seal	Low	Medium	Good	Good
Cape Seal	Low	Medium	Good	Good
Cold mix asphalt	Low	Medium	Good	Good
Pen. Macadam	Low	Medium	Good	Good

3.4 Economic and Financial Issues

3.4.1 Life cycle cost analysis of LCS options

In order to determine the cost-effectiveness of the different types of LCSs, it is necessary to undertake a financial life cycle cost analysis, where all construction and maintenance costs occurring during the life of the road are taken into account. The inputs for this analysis include:

- Discount rate – assumed as 12%
- Analysis period – assumed as 15 years at which time rehabilitation will be required.
- Seal construction costs – based on actual construction costs of the trial sections on the Busamaga-Magada-Bumulya road in Mbale but adjusted (+ 25%) to take account of the contractor's mobilisation/demobilisation, overheads, risk and profit.
- Seal maintenance costs – periodic maintenance only as it is assumed that the recurrent costs will be reasonably similar for all the surfacings and can be disregarded in the comparative life cycle cost analysis.

In the life-cycle analysis process, the various LCS options are compared by converting all the costs that may occur at different times throughout the life of each option to their present day values. Such values were obtained by adopting a standard discounted cash flow technique to determine the Present Value of costs of the LCS options. On that basis, the life cycle cost of a range of LCS options that are potentially suitable for application in Uganda are summarised in Table 3-9.

Table 3-9: Cost effectiveness of LCS options

Option No.	LCS Option Type	Construction Cost (US$/m²)	Life cycle cost (US$/m²)	Cost-effective-ness rating
16	Double Otta seal (screened natural gravel)	10.97	10.14	1
3	Double sand seal (river sand)	7.44	10.18	2
17	Double Otta seal (crushed aggregate)	11.70	10.82	3
14	Single Otta seal (screened gravel) + river sand seal	9.88	10.88	4
18	Cape Seal	9.83	11.20	5
1	Single sand seal (river sand)	4.02	11.38	6
8	Single Surface Dressing + sand seal (river sand)	6.30	11.60	7
4	Double sand seal (crusher dust)	8.66	11.85	8
15	Single Otta seal (screened gravel) + crusher dust	10.48	11.94	9
9	Single Surface Dressing + sand seal (crusher dust)	6.46	11.97	10
12	Single Otta seal (screened natural gravel)	5.48	12.27	11
10	Double surface dressing	9.12	12.61	12
13	Single Otta seal (crushed aggregate)	5.85	12.98	13
6	Double slurry seal	9.49	12.99	14
7	Single surface dressing (SSD)	5.19	13.03	15
21	Cold mix asphalt (crushed aggregate)	9.47	13.13	16
2	Single sand seal (crusher dust)	4.68	13.25	17
20	Cold Mix Asphalt (screened natural gravel)	9.35	13.30	18
11	Inverted double surface dressing	10.07	13.62	19
19	Penetration Macadam	11.98	14.02	20
5	Single slurry seal	5.13	14.52	21

The following conclusions may be drawn from the results of the life cycle cost analysis:

1. The most cost-effective seals are the graded aggregate Otta seals and double sand seal using screened aggregate, followed by the single sand seal and surface dressings capped with river or crusher dust seals. This is due largely to the enhanced durability of these close-textured, relatively dense seals which results in lengthened recurrent maintenance intervals and consequent lower life cycle costs.

2. The least cost-effective seals are those that require relatively large bitumen application rates (a high cost item accounting typically for approx. 75% of the total cost of the surfacing) and which, nonetheless, do not produce a very durable seal. They include Penetration Macadam, inverted double surface dressing and cold mix asphalt.

3.4.2 Maintenance funding requirements and sources

It is absolutely essential that the investments made by GoU in upgrading gravel roads to a sealed standard using LCS technology are preserved through timely maintenance. Unfortunately, reliance on the fiscus for maintenance funding, more so for district roads, has proven to be highly problematic in Uganda. This has prompted the GoU to establish a Road Fund which derives its revenue from road user charges. Most of this revenue, which is currently not ring-fenced, is then allocated to the roads agencies responsible for the maintenance only of national (UNRA) and, to a lesser extent (35% of total revenue) to urban and district roads.

The LCS works to be undertaken in the districts are, strictly speaking, of a development rather than maintenance nature and, as a result, would not be eligible for funding by the Road Fund. However, it is also clear from the founding URF Act, 2008, that the governing legislation stipulates that a *commercialised* approach to road maintenance should be followed. In this regard, LCS technology does offer better "value for money" over the more traditional and costly (in life cycle terms) gravel maintenance option which has become discredited in many countries.

From discussions held with the Road Fund, it is apparent that this organisation is open to persuasion to amend its legislation to allow the use of Road Fund allocations to the districts to be used for LCS works. However, this is contingent upon the organisation's receipt from MoWT of a well documented proposal which justifies the economic viability of the LCS technology and quantifies the benefits of this approach over the previous gravel maintenance approach followed in the districts.

3.5 Selection of Options

3.5.1 Selection framework

The selection of LCS options should be based on a wide array of factors, largely of a technical, economic and social nature, that affect the preferred choice of surfacing. In the final analysis, such a choice will be very project specific as factors such as plant or materials availability, site conditions and local maintenance capability may well influence the final choice, rather than solely cost-effectiveness.

Table 3-10 provides a general framework for selecting a particular type of LCS. The table assumes no constraints on plant or materials availability and can be adapted to suit local conditions and subsequently used to make a final choice of surfacing options for the consideration of decision-makers.

Table 3-10: LCS selection guide

Parameter	Surfacing Type													
	SSS	DSS	SSIS	DSIS	SSD	SSS+SS	DSD	ISD	SOS	SOS+SS	DOS	CS	PM	CMA
Cost effectiveness	Poor	Good	Poor	Fair	Poor	Good	Fair	Poor	Fair	Good	Good	Good	Poor	Poor
Ease of design	Good	Good	Good	Good	Fair	Fair	Fair	Fair	Poor	Poor	Poor	Fair	Fair	Fair
Suitability for lab-based methods	Good	Good	Good	Good	Fair	Fair	Fair	Fair	Poor	Poor	Poor	Fair	Fair	Fair
Service life	Poor	Poor	Poor	Poor	Poor	Fair	Fair	Fair	Fair	Good	Good	Good	Good	Fair
Traffic level	Poor	Poor	Poor	Poor	Poor	Fair	Good	Good	Fair	Good	Good	Good	Good	Good
Impact of traffic turning action	Poor	Poor	Poor	Poor	Poor	Fair	Fair	Fair	Fair	Good	Good	Good	Good	Good
Gradient w.r.t constructability	Common practice is not to use sprayed seals on longitudinal gradients in excess of 12%. Where emulsion or cutback binders are used, the gradient should not exceed about 6%.													
Sensitivity to material quality	Good	Good	Good	Good	Poor	Poor	Poor	Poor	Fair	Fair	Fair	Poor	Fair	Fair
Binder requirements	Good	Good	Good	Good	Good	Good	Good	Good	Fair	Fair	Fair	Good	Good	Good
Sensitivity to base quality	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Ease of construction	Good	Good	Good	Good	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Sensitivity to maintenance	Poor	Poor	Poor	Poor	Poor	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair

Legend	
Code	**Description**
SSS	Single sand seal
DSS	Double sand seal
SSIS	Single slurry seal
DSIS	Double slurry seal
SSD	Single surface dressing
SSS+SS	Single surface dressing + sand seal
DSD	Double surface dressing
ISD	Inverted surface dressing
SOS	Single Otta seal
SOS+SS	Single Otta seal + sand seal
DOS	Double Otta seal
CS	Cape seal
PM	Penetration macadam
CMA	Cold mix asphalt

Green (Good)	Relatively good/high/suitable
Yellow (Fair)	Relative moderate/fair
Red (Poor)	Relatively poor/low/unsuitable

3.5.2 Preferences of MoWT

The preferences of MoWT in terms of all the parameters and associated choice of LCS type may be assessed under the following headings:

(a) **Institutional arrangements**: The options to be considered centre on whether or not the provision of LCS technology (design, preparation of tender documents & tendering of projects and supervision of construction) should be undertaken in-house, i.e. within the districts or outsourced to private sector consultants.

Whilst it may be feasible to undertake the trial contracts in-house with the assistance of MELTC, the ability to also do so for the RTI programme and longer term GoU programme seems questionable due to capacity constraints within the districts. Consideration should therefore be given to outsourcing this activity to private sector consultants. This will require initially the provision of training, an activity that can be undertaken by MELTC, as discussed in Section 3.2.2.

(b) **Labour-based versus equipment based LCS technology.** The current focus of the RTI program is to utilise labour-based approaches which offer job opportunities for people from poor rural households as well as to create business opportunities for labour-based trained contractors. This approach is very appropriate for the construction of relatively low trafficked district rural, urban and community access roads. However, should UNRA also embark on the application of LCS technology to the more heavily trafficked national roads, then consideration may have to be given to the use of more equipment based approaches to ensure the higher productivity levels demanded in the construction of such roads.

(c) **Choice of surfacing type:** As indicated in Table 3-10, the choice of LCS is guided by a range of factors which are not only project specific, but which are also influenced by whether the roads are located in a rural or urban environment. In a rural environment, for example, whilst it may be quite acceptable to tolerate seals which require relatively frequent maintenance interventions, this may well not be the case in an urban environment where traffic delays due to frequent maintenance works can be relatively costly and politically unacceptable and, as a result would dictate a relatively durable, long-lasting seal.

3.6 LCS Cost Estimates

3.6.1 Construction scenarios

Two construction scenarios need to be considered in the implementation of the LCS trial contracts and subsequent LCS full-scale programme as follows:

(a) Scenario 1: The LCS is applied immediately after the gravel road is brought to a standard appropriate for sealing. Ideally, any maintenance activities for a gravel road which is planned to be upgraded to a sealed standard should be carried out just prior to the upgrading works.

The above approach will ensure that scarce resources are used as efficiently as possible and any expenditure on maintenance will be full preserved by the road upgrading to a LVSR standard. **This is the approach envisaged in the Danida project document, i.e. *the LCS technology would be applied on road sections where the preparatory pre-sealing works as described above had already been carried out.***

(b) Scenario 2: The road has been constructed to a gravel standard not entirely adequate for receiving the LCS technology and, moreover, has been left for some time before applying the LCS technology. In this scenario, there will be need to upgrade the road to ensure that is adequate for sealing, as well as to carry out some reshaping before adding the supplementary base layer. Such works would typically include the following, where required:

- Drainage improvements.
- Embankment raising.
- Reshaping/gravelling works.

Other miscellaneous works associated with the road upgrading.

3.6.2 Cost estimates

Based on the most recent estimates from the MELTS trials, the costs estimates for scenarios 1 and 2 are as follows:

(a) **Cost estimate – scenario 1:** In this scenario, as described in Section 3.6.1 (a) above, the works comprise the application of a LCS to the previously upgraded gravel road. The average costs per km for the three types of seal likely to be constructed in the districts (double sand seal, single surface dressing + sand seal and single Otta seal for a 4.5 m carriageway is as follows:

i. Cost of seal only = UGX 75 million
ii. Cost of priming = UGX UGX 25 million/km
iii. Total cost + UGX 100 million/km.

(b) **Cost estimate – scenario 2:** In this scenario, as described in Section 3.6.1 (b) above, the average costs/km is estimated as follows:

i. Cost of base preparation = UGX 50 million/km
ii. Cost of seal only = UGX 75 million
iii. Cost of priming = UGX UGX 25 million/km
iv. Cost of Preliminary and General (P & G) items = UGX 20 million/km
v. Profit, risk and overheads = UGX 10 million/km
vi. Total cost = UGX 180 million/km

3.7 Implementation of Trial Contracts

3.7.1 General approach

The general approach envisaged for the implementation of the trial contracts is premised on the following assumptions:

1. The private contractors that have received training at MELTC will be offered the trial contracts in the districts on a non-competitive basis as part of practical training.

2. The design of the trial projects has been undertaken jointly by MELTC and technical staff in the districts to ensure acceptable outputs.

3. The trial contracts will be carried out by 25 contractors in 23 districts.

4. The funding available for the trial contracts (UGX 1.25 billion) was expected to provide for the construction of about 1.5 km trial contracts in each district, or a total of about 34.5 km in all. This estimate was apparently based on the assumption that the LCS will be applied on road sections in connection with other rehabilitation works, including the pre-sealing works comprising base preparation, road drainage, etc. (Danida, 2009).

From the site visits made to three typical districts (Kumi, Lira and Gulu), coupled with a review of the proposed project designs and discussions with technical staff, the following observations are made:

1. The designs for the trial contracts need to be harmonised as there are a number of differing input assumptions regarding such factors as design life, vehicle equivalence factors, etc.

2. There was apparently insufficient attention given in the districts to the necessary improvement of the drainage along the project roads which is critical to their long-term performance;

3. Varying amounts of pre-sealing works will need to be carried out before construction of the LCSs.

3.7.2 Scope of implementation programme

The scope of the implementation programme is dictated by the cost estimates related to the two construction scenarios presented in Section 3.6.2. On this absis, for a given budget of UGX 1.25 billion, the following trial contract scenarios are possible:

Scenario 1: *Budget spent only on sealing works at UGX 100 million/km.*

Total kilometrage possible = 12.5 km which equates to approx. 500 m per trial contract for each of the 25 contractors in the 23 districts. **This kilometrage is approx. 36% of that originally envisaged.**

Scenario 2: ***Budget spent on pre-sealing preparatory works + LCS works at UGX 180 million/km.***

Total kilometrage possible = 7.0 km which equates to approx. 280 m per trial contract for each of the 25 contractors in the 23 districts. **This kilometrage is approx. 20% of that originally envisaged.**

Normally, a minimum trial contract length of 300 m would be desirable for each type of seal constructed to allow the contractor to become reasonably well versed in the construction technology. Any lesser kilometrage would almost, if not, defeat the objective of the exercise. Thus, assuming the more realistic Scenario 1 above, the following implementation options are feasible:

a. Scenario 1 above:

- All 23 districts involved with implementing 1 – 3 LCS options:
- (1) Let all 25 contractors undertake 1 x 500 m length of 1 No. type of LCS
- (2) Let 12 contractors undertake 1 x 500 m length of 2 No. types of LCS.
- (3) Let 8 contractors undertake 1 x 500 m length of 3 No. types of LCS

Each of the above options provides advantages and disadvantages and, in the final analysis, a policy decision will have to be made regarding the preferred option.

b. Scenario 2 above.

- All 23 districts involved with implementing 1 – 3 LCS options:
- (1) Let all 25 contractors undertake 1 x 280 m length of 1 No. type of LCS
- (2) Let 12 contractors undertake 1 x 280 m length of 2 No. types of LCS.
- (3) Let 8 contractors undertake 1 x 280 m length of 3 No. types of LCS

Each of the above options provides advantages and disadvantages and, in the final analysis, a policy decision will have to be made regarding the preferred option.

In summary:

a. The expectation that the LCS technology would be applied on road sections in connection with other rehabilitation works has not been realised in practice. In fact, such preparatory pre-sealing works, such as base preparation and drainage, are critical to the performance of the sealed roads.

b. The original budget for the LCS trial contract was made in advance of execution of the LCS trials carried out by MELTC. In the event, this estimate has turned out to be lower than that required to achieve the desired 34.5 km length of trial contracts.

c. On the assumption that the budget is fixed at UGX 1.25 billion, it will not be possible to undertake the trialling of at least three LCS options in each of the 23 districts involving 25 previously trained contractors. Some compromise will be necessary either in terms of utilising a lesser number of contractors or undertaking a lesser number of LCS options than desirable in each district. To retain contractor the interest of the contractors, the latter option may be preferable.

3.8 Implementation of LCS Programme

3.8.1 Envisaged versus actual programme

The original goal of the RTI was to achieve a target of 300 km of district roads sealed with LCSs during its four years program period (FY 2010-2013). The budget for achieving this target was estimated at DKK 36 million **(= UGX 15 billion)** and formed part of the Danish Ministry of Foreign Affairs support to GoU (Dandia, 2009). It was assumed that the LCSs would be applied on road sections in connection with other rehabilitation works, i.e. preparatory road base preparation works would not be required prior to undertaking the sealing works. In practice, this is not the case and such preparatory works will be required to be undertaken before constructing the LCS works.

Due to inflation of about 17% p.a over the three year intervening period since the budget was first prepared (2009), the amount currently available for the RTI programme is now estimated to be of the order of **UGX 9.5 billion.** This budget will realise the following construction options:

(a) Scenario 1: ***Budget spent only on sealing works at UGX 100 million/km.***

In this scenario, a total RTI programme of **95 km** of LCS works is possible with the available budget of UGX 9.5 billion, a reduction by about 32% of the total kilometrage originally envisaged. Alternatively, a revised budget of UGX 30 billion would be required to achieve the 300 km target envisaged.

In terms of achieving the budget constrained construction target of 95 km of LCS works, the 25 previously trained contractors will be required to achieve a productivity of about 4 km/year. Assuming that the delayed RTI program can commence in April 2013 after completion of the necessary design and tendering processes in the districts, then the reduced 95 km target should be easily achievable. However, if the budget was available to allow the construction of 300 km of LCS works, then achievement of this kilometrage (approx. 12 km/year) might not be unattainable with just the 25 contractors that have already been trained.

(a) Scenario 2: ***Budget spent on pre-sealing preparatory works + LCS works at UGX 180 million/km.***

In this scenario, a total RTI programme of **53 km** of LCS works is possible with the available budget of UGX 9.5 billion, a reduction by about 18% of the total kilometrage originally envisaged. Alternatively, a revised budget of UGX 54 billion would be required to achieve the 300 km target envisaged.

In terms of achieving the budget constrained construction target of 53 km of LCS works, plus the necessary road base preparation and drainage works, the 25 previously trained contractors will be required to achieve a productivity of about 2 km/year. Assuming that the delayed RTI program can commence in April 2013 after completion of the necessary design and tendering processes in the districts, then the reduced 53 km target should be easily achievable. However, if the budget was available to allow the construction of 300 km of LCS works, then achievement of this kilometrage (approx. 12 km/year) might not be unattainable with just the 25 contractors that have already been trained.

3.9 Assumptions and Risks for LCS Implementation Under RTI

The following are the various assumptions, risks and mitigation measures for LCS implementation under RTI:

3.9.1 Assumptions

- There is in place a nationally accepted policy and strategy for implementation of LCS technology.
- MELTC can continue to play its mentorship role to Districts, Urban Councils, UNRA, contractors and other stakeholders.
- The budgets estimated for the trial contracts and the roll out of the RTI program in the 23 districts as well as in GOU's NDP are sufficient to achieve the anticipated targets of 37.5 km, 300 km and 10,000 km respectively.
- Contractor ability to procure all equipment requirements (e.g . BD for some seal types).
- Sufficient capacity in Districts to implement roll out of LCS projects.
- Sufficient, sustained, funding for maintenance of LCS roads.

3.9.2 Risks

- A policy and strategy for implementation of LCS technology is not yet not firmly embedded in NDP and accepted by all stakeholders.
- Support to MELTC is under threat and the organization may be unable to fulfil its anticipated role in nurturing and championing LCS technology in Districts, UNRA, etc.
- The available budgets are grossly inadequate to achieve the anticipated targets resulting and could result in disillusionment and waning support for LCS technology by donors and GoU.
- The contractors may be financially constrained from purchasing the plant required for all seal types, resulting in exclusion of some seal types (e.g. Otta Seal)
- Insufficient institutional capacity in Districts to implement the rollout of the RTI program after completion of the trial contracts.
- Insufficient and erratic funding for maintenance of LCS roads.

3.9.3 Mitigating measures

- Quantify life cycle cost benefits of LCS technology and highlight significant benefits to national socio-economic growth and development.
- Develop realistic, detailed budgets for implementing LCS technology
- Prepare LCS project document highlighting viability of LCS technology, including its adaptability and flexibility to local conditions and materials, simplicity of use, reduced environmental impact, etc.

- Promote inclusion of LCS policy and strategy in NDP
- Use LCS project document to convince Road Fund of efficacy of using maintenance funds for LCS roads.

3.10 Promotion of LCS Technology

The typical pathway from LCS research to implementation of any new technology is illustrated in Figure 3-1. Such an approach should be followed in Uganda if it is to be implemented in a sustainable manner.

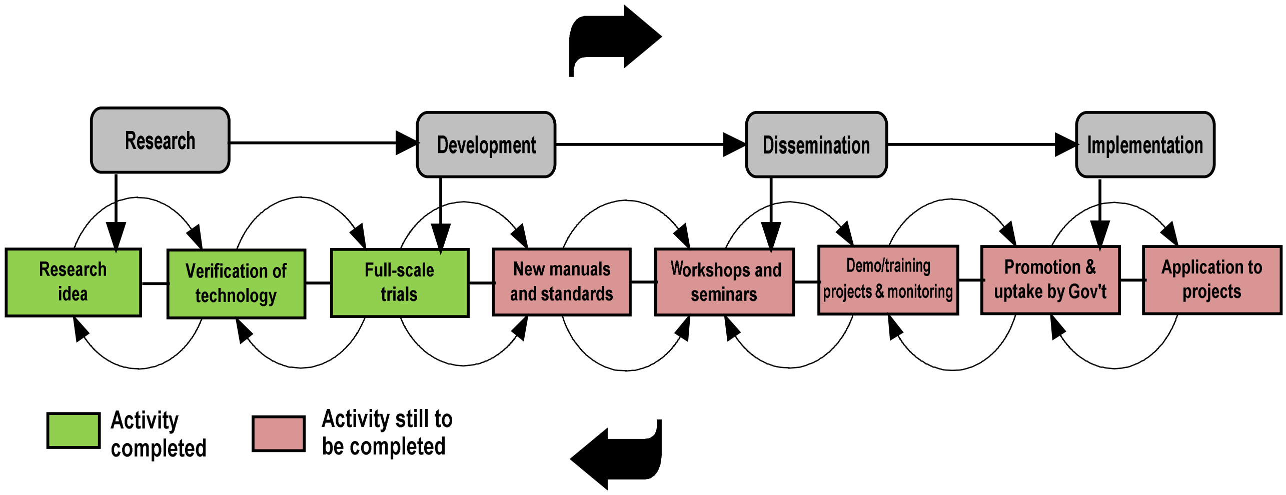


Figure 3-1: Pathway from research to implementation
(adapted from TRB Special Report 256, 1999)

As indicated in Figure 3-1, the following activities in the technology transfer chain have already been completed in Uganda:

- **Research idea**: initiated by Danida in the RTI program (Danida, 2009)
- **Verification of technology** – already proven in the region
- **Full-scale trials** – already undertaken by MELTC

The following activities are still required to complete the pathway to full implementation of LCS technology:

- **New manuals**: The current MELTC guidelines are a step in the right direction but do not, in their current form, fulfil the requirements of a manual on low volume sealed roads, including appropriate designs and specifications for pavements and LCSs. The current Uganda Pavement Design Manual is more suited to high volume roads and does not deal with LCSs. Thus, until a new, nationally approved low volume sealed roads manual is in place, the implementation of LCS technology will be impeded, if not suppressed.

- **Workshops and seminars:** Promotion of the LCS technology to a wider, national audience is required to obtain understanding and buy-in of the new technology.

- **Demonstration/training projects and monitoring**: This is still to be undertaken in the form of the trial contracts in the 23 districts in Uganda. This activity is a pre-requisite to further training of local contractors as a stepping stone to their undertaking of further projects in the RTI program. Monitoring of these trial projects is also of paramount importance to provide inputs for refinement of the LCS designs and construction.

- **Promotion and uptake by Government:** This is a critical activity which will ultimately manifest itself in the form of GoU policy on LCS technology in their NDP. However, before this can happen, it will be necessary to produce a well motivated document justifying the viability of the LCS technology. This review can provide an input to such a document which will give confidence to MoWT and other stakeholders that Uganda is moving in the right direction with LCS technology.

3.11 Sustainability of LCS Technology

From experience in the region, the introduction of LCS technology in Uganda will only be successful in the long term if it satisfies various so-called sustainable “dimensions of sustainability” as illustrated in Figure 3-2 and discussed further below.

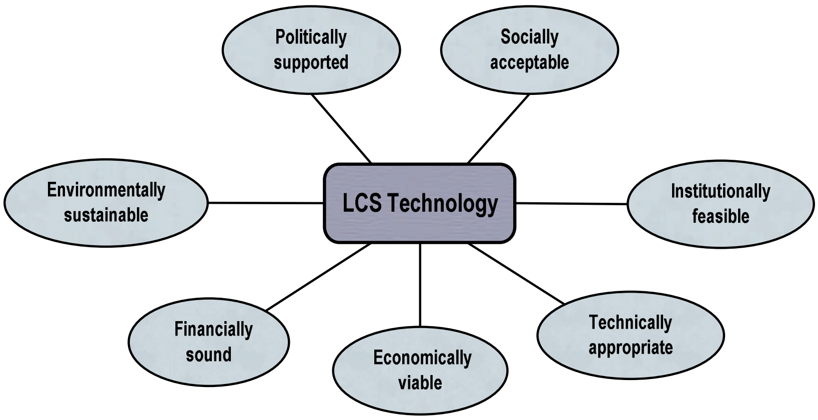


Figure 3-2: Sustainable dimensions of LCS technology

(a) **Political support**: There is apparent political support for LCS technology in Uganda in that the GoU has indicated in its NDP an intention to improve up to 10,000 km using this technology. However, this support will only be confirmed if a clear policy and strategy is developed by MoWT. The development of such a document is of high priority as it is also required by the Uganda Road Fund to facilitate the amendment of its legislation to allow Road Fund allocations to the districts to be used for LCS works. This dimension has only been partially satisfied and urgent action is required to achieve full political support.

(b) **Socially acceptable**: The implementation of LCS technology is premised on the use of labour-based technologies to create much needed employment in rural areas. This dimension is fully satisfied.

(c) **Institutionally feasible**. Institutional capacity is likely to be adequate in the short term for the undertaking of the trial contracts but, due to capacity constraints, is unlikely to be adequate for the roll out of the RTI programme and, even less so, in the longer term. Outsourcing of LCS design and supervision works to the private sector is a logical option but this will require a concerted training effort which MELTC, with sustained support, is fully capable of providing.

(d) **Economically viable**: There are a wide range of LCS options which can be adopted. The selection of an option on the basis of its cost-effectiveness will ensure that the technology is economically viable.

(e) **Financially sound**: Preservation of the investments made in LCS technology hinges critically on the adequacy of funding for maintenance. This has always been a major problem and it is essential that the Road Fund allocations to the districts can be used for maintenance of LCS works which offer much better value for money than if such allocations were to be used for maintenance of gravel roads. Amendment of the Road Fund legislation to allow their funding to be used for maintenance of LCS works is a high priority.

(f) Financially sustainable: Adoption of an LCS strategy will reduce the depletion of a dwindling resource – gravel – which, in the process of its exploitation, is also causing serious environmental problems. Sealed roads also reduce other adverse impacts such as dust generation which can cause health problems in built-up areas and increase traffic accidents.

In summary, the sustainability of LCS technology can be illustrated in the form of a radar chart as presented in Figure 3-3. Each element has been rated out of a maximum of 10 from which the most deficient elements of sustainability become readily apparent

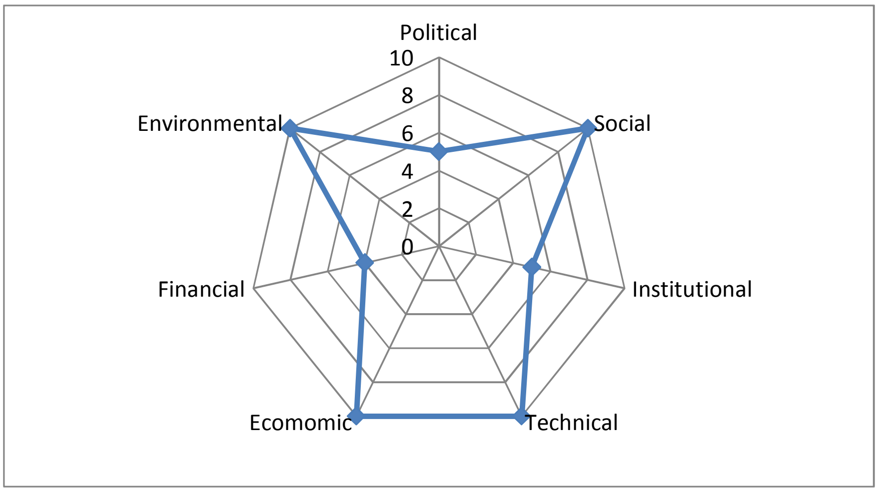


Figure 3-3: Assessment of sustainability of LCS technology in Uganda

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Summary of Conclusions

The following is a summary of the conclusions arising from the review of LCS technology options in Uganda:

4.1.1 Institutional issues

Training curriculum

4. The proposed training curriculum does not cover a number of important topics related to LCS implementation, including borrow pit management, road safety and cost analysis of surfacing options.

5. The organisation of cross-cutting issues and treatment of drainage need to be enhanced.

Institutional capacity

6. Institutional capacity in the districts is likely to be adequate in the short term to oversee the implementation of the trial contracts but, due to capacity constraints, is unlikely to be so in the medium to long term for the rollout of future LCS programs.

7. MELTC is well placed to expand its training programme to meet the demand for future training in LCS technology in both the public and private sectors.

4.1.2 Technical issues

Base preparation

8. For the LCS trials, the compactive effort used, and density obtained, in the running surface of the existing road and the imported pavement layer(s) does not result in optimal utilisation of local materials and the provision of the most economic pavement structure.

LCS trials and early performance

9. About one year after construction, all the seals appear to be performing satisfactorily although a number of them appeared to be binder hungry which could affect later performance.

Choice of LCS options

10. The LCS options trialled are common to the region but did not include two other feasible options, namely: Otta seal using screened (rather than crushed) aggregate and Cape seal - essentially a surface dressing with a slurry capping.

Viability of LCS options

11. To varying extents, depending on project specific situations, all the LCS options are viable in the context of relatively small-scale works undertaken by small-scale contractors providing modest levels of productivity.

Availability of materials and plant for LCS options

12. In general, aggregate availability is region specific and all types of aggregates may not necessarily be available at reasonable haulage from a particular district.

13. Hand-knapped or screened aggregate rather than machine crushed aggregate are the preferred options for constructing LCSs using labour-based methods.

14. The binders necessary for construction of the LCSs, emulsion or penetration grade, are not available locally and have to be imported. These binders are a high cost component of the LCSs (on average about 75% of the total cost of the seal).

15. Emulsions are the preferred option for constructing LCSs using labour-based methods.

16. Plant requirements are seal specific with most LCS options requiring relatively small and inexpensive mechanised plant (e.g. concrete mixer, pedestrian roller, hand-lance sprayer) which is normally readily available to contractors. Some seal types require larger and more expensive mechanised plant (e.g. bitumen distributor and heating device) which may not be easily available to contractors.

Adaptability of LCS options to labour-based technology

17. The LCS options trialled provide varying levels of adaptability to labour-based technology with the most adaptable ones allowing the use of hand-knapped or screened gravel, cold applied binders (emulsion) and relatively small mechanised plant.

Maintenance needs and methodologies

18. All the LCSs will require some form of routine, recurrent or periodic maintenance, the type and extent of which will depend on the durability of the seal which in turn is related to factors such as quality of pavement construction, environment, road alignment (gradient and turning movements) and traffic volume and composition.

4.1.3 Economic and financial issues

Cost-effectiveness

19. Based on a life-cycle cost analysis, the most cost-effective seals are the graded aggregate Otta seals and the least cost-effective include Penetration Macadam, inverted surface dressing and cold mix asphalt.

Maintenance funding requirements and sources

20. Funding for maintenance of the LCS projects in the districts is a major problem which, if not addressed, will most likely jeopardize the investments made in LCS technology.

21. Road Fund allocations to the districts is currently confined to maintenance of gravel roads only. However, LCS technology does provide better value for money and the URF is open to persuasion from MoWT to amend its legislation to allow the use its funding for LCS works contingent upon receipt of a well documented proposal which justifies the economic viability of LCS technology.

4.1.4 Contractual and implementation issues

Selection of LCS options

22. The selection of LCS options very project specific and is influenced by a wide array of factors including plant or materials availability, site conditions and local maintenance capability. A framework including these various factors will facilitate the selection of the preferred choice of LCS.

Preferences of MoWT pertaining to choice of LCS type

23. The preferences of MoWT pertaining to all the parameters and associated choice of LCS type will require their consideration of the following:
    a. *Institutional arrangements*: In-house or outsourcing of design and supervision of LCS works in relation to capacity dictates.
    b. *Labour-based versus equipment based technology:* In relation to the application of LCS technology on low-trafficked (mostly district) or high-trafficked (mostly national) road.
    c. *Choice of surfacing type:* In relation to application of LCS technology n a relatively low-trafficked rural environment or relatively high-trafficked urban environment.

Approach for implementation of trial contracts

24. The expectation that the LCS technology would be applied on road sections in connection with other rehabilitation works has not been realised in practice. Such preparatory pre-sealing works will be required prior to the application of the LCSs.

25. The original budget for the LCS trial contract which was made in advance of execution of the LCS trials carried out by MELTC has turned out to be lower than that required to achieve the desired 34.5 km length of trial contracts.

26. Based on a budget of UGX 1.25 billion, it will not be possible to undertake the trialling of at least three LCS options in each of the 23 districts involving 25 previously trained contractors. Some compromise will be necessary either in terms of utilising a lesser number of contractors or undertaking a lesser number of LCS options than desirable in each district.

Revised target for LCS programme

27. Based on appropriate adjusted construction emanating from the MELTC trials and a current budget availability of UGX 9.5 billion, the revised target for the RTI programme will be as follows:

    (a) Scenario 1 – About 95 km (Budget spent only on LCS works only at UGX 100 million/km).

    (b) Scenario 2 – About 53 km (Busget spent on spent on pre-sealing preparatory works + LCS works at UGX 180 million/km.

    In both of the above scenarios, the possible targets are well less than the 300 km originally envisaged.

Assumptions and risks for LCS implementation under RTI

28. There are a number of assumptions and risks associated with LCS implementation under RTI that need to be addressed by the adoption of a number of mitigation measures as detailed in Section 3.5.5 of this report.

Promotion and implementation of LCS technology

29. In terms of the typical pathway from research to implementation of LCS technology, the preparatory links in the technology transfer chain (research idea, verification of technology and full-scale trials have been accomplished. However, a number of other important links which are critical to the attainment of sustainable LCS implementation still need to be addressed (production of new manuals, holding of workshops and seminars, demonstration/training projects and monitoring and production of documentation required for uptake by GoU.

30. Some of the necessary dimensions of LCS sustainability have already been satisfied (social, technical, economic and environmental) but other equally important dimensions are still to be satisfied (political, institutional and financial).

4.2 Summary of Recommendations

The following is a summary of the recommendations arising from the review of LCS technology options in Uganda:

4.2.1 Institutional issues

Training in LCS technology

1. The scope of the training curriculum at MELTC should be expanded to include the following topics:
    a. Borrow pit management
    b. Road safety
    c. Life Cost analysis of surfacing options

    And should be enhanced to achieve:
    d. Improved organisation of cross-cutting issues
    e. Expanded treatment of drainage and quality assurance requirements

Institutional capacity

2. MELTC should be financially supported to carry out a future expanded LCS training programme based on a training needs assessment.

4.2.2 Technical issues

Base preparation

3. Where practicable, the compaction of the base and subbase layers should be specified as a minimum of 95% and 98% Mod. AASHTO respectively (or even higher, where field trials indicated this is practicable) by employing heavier compaction plant.

LCS trials and early performance

4. The LCS trials should be monitored to assess the performance of the surfacings in relation to the adequacy of the binder content which, if necessary, should be amended as appropriate.

Choice of LCS options

5. The use of an Otta seal surfacing using screened gravel and a Cape seal should be considered for future trialling.

4.2.3 Economic and financial issues

Maintenance funding sources

6. A well documented proposal which justifies the economic viability of LCS technology should be prepared by MoWT for URF to facilitate the latter's amendment of their legislation to allow the use of Road Fund allocations to be used for maintenance of LCS works.

4.2.4 Contractual and implementation issues

Promotion and implementation of LCS technology

7. The following critical links in the technology transfer chain should be address as soon as possible:
    a. The development of a Manual on Low Volume Sealed Roads including the use of LCSs.
    b. The holding of targeted workshops and seminars to promote the merits of LCS technology
    c. The execution of the trial contracts and their subsequent monitoring to refine, where necessary, the design and/or construction of LCSs.

8. The following dimensions of LCS technology should be addressed:
    a. *Political:* The development of a well motivated document that justifies the viability of LCS technology (also required by URF).
    b. *Institutional:* The undertaking of a training needs assessment in LCS technology as a basis for expanding the MELTC training program to meet the demand in both the public and private sectors.
    c. *Financial*: The preparation of a well motivated document that justifies the viability of LCS technology (similar document as required to satisfy the political dimension).

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ANNEX A – Terms of Reference

Consultancy
To review the application of low cost seal technology options on low volume roads in Uganda and to carry out some cost-benefit analysis with regard to these options

1.0 Background

1.1 Introduction

The Rural Transport Infrastructure (RTI) is a component of the Danida four-year U-Growth programme (2010-2013). The objective of the RTI component is to develop and maintain district, urban and community access roads to promote cheaper, efficient and reliable transport services to facilitate access to markets, and improve access to extension services, to agricultural inputs and to social services. RTI is implemented using the labour-based methodologies as a continuation from the previous programmes. The use of labour-based methods offers job opportunities for women and men from poor rural households. It also creates business opportunities for local labour-based trained contractors and thus contributes to the local economic growth.

The RTI is supposed to develop the low-cost seal (LCS) technology on low volume roads. There has been limited research done before the introduction of LCS technology in Uganda. The LCS technology however provides a viable alternative for road surfacing to address the scarcity of good gravel experienced in Uganda currently by providing durable road surfacing which reduces on maintenance needs and gravel loss, and hence the need for the natural gravel resources. Use of LCS will in turn also reduce both transport time and maintenance costs. The Government of Uganda has plans to use the LCS technology under the National Development Plan (NDP) and envisages improving up to 10,000km of districts roads using low cost seal in five years (2010/11-2014/15). The introduction of LCS in Uganda requires a clear policy and strategy to be developed by the Ministry of Works and Transport. The LCS applications will also give the Mount Elgon Labour-Based Training Centre (MELTC) an opportunity to expand their current training programmes to the Urban Councils (urban roads) and the National Roads Authority.

The RTI was expected to achieve a target of 300 km of district roads sealed with low-cost seal during its four years' program period (2010-2013). Due to some delays in the implementation, the RTI targets may not be realised. Furthermore, the next phase of the U-Growth Programme (U-Growth 2) may not include direct support to MELTC. In addition, questions are raised about the current cost of the different options proposed under the current trials. The level of ambition and the sustainability of the LCS technology as envisaged from the RTI needs to be reviewed.

1.2 Progress on low cost seal implementation

The Ministry of Works and Transport in October 2010 engaged a consultant (Transport Research Laboratory, TRL) to prepare training modules, to train MELTC personnel in labour-based low-cost sealing (classroom and on-site demonstrations) and to prepare guidelines and specifications for use of locally available materials on low-volume traffic roads including developing quality control measures for the low-cost sealing of roads. The Consultant submitted their final reports in August 2011 and the findings of the demonstrations are to be disseminated to the wider stakeholders.

The staff from MELTC have so far received the required training on low-cost seal technology. 11 staff from MELTC received both classroom training and practical demonstration of different options of low cost seals on a 0.6 km trial section of road in Mbale. In turn, MELTC embarked on training of district technical staff from 23 districts in the North on low cost seal technology. The training targets both the district staff and private contractors. The main emphasis of the LCS training is use of labour based methods which can be adapted or designed to the existing conditions and locally available resources and materials in the areas where the sealing works take place. It was also envisaged that use of Otta seal, which is well known in Africa (e.g. Kenya and Botswana) would be promoted to the extent possible.

The Joint Transport Sector Review Mission in October 2011 expressed the need for the right option(s) to be selected before systematic training is planned and undertaken. Since the training had already commenced and the development of the curriculum for low-cost seal is in final stage, there is need to carry out a review to better inform the process. The curriculum is expected to evolve as experience is gained from further pilot tests and feasibility assessment. It is also planned that the private contractors receiving training at MELTC will first be offered trial contracts at the districts as part of practical training.

1.3 LCS provides an opportunity for MELTC

MELTC currently has a well-established capacity to train public servants both at the central and local governments and also the private contractors and consultants. The scope of training is however limited as MELTC capacity to market its services to a wider audience is a little bit constrained. The introduction of low-cost seal and the associated training of urban and local government staff and private contractors and consultants provide MELTC an opportunity to market its services to wider stakeholders. MELTC will also be able to open its doors to train the Uganda National Roads Authority (UNRA) staff, especially those engaged in the maintenance of national roads. UNRA is already in a process of looking into LCS options for some of their low-volume National Roads. Furthermore, LCS technology adoption provides possibilities for the development of research in collaboration with private/public sector institutions and international organizations.

For the low cost seal options to be implemented and rolled out to the districts, the following, among others, are required:

- Identification of suitable options for low-cost sealing based on the best practices and experience from countries in the region (based on technical and financial feasibility assessment);
- Development of a curriculum, training modules and manuals for low-cost sealing course to be offered at MELTC; and
- Development of Standard specifications guidelines and work procedures for application of LCS.

Furthermore, it should be emphasised that for the LCS technology to be viable, it must demonstrate low cost options, be flexible and adaptable to the local conditions, materials and technology (simplicity of use).

2. Objective

The objective of this assignment is to provide a concrete justification for the application of the low cost seal technology which is appropriate for the local conditions prevailing in the districts under the current RTI support. The justification shall include an assessment of the various proposed technology options, cost benefit analysis of the different options (including life cycle costs), assessment of the availability of equipment and materials, adaptability of the various options to labour-based technology, maintenance needs and methodologies as well as considerations of wider sustainability issues (e.g. financial implications and government commitment). Furthermore, the assignment shall also inform about what realistic targets for LCS can be achieved by the end of the RTI programme.

3. Outputs

The main output for this assignment shall be a concise but elaborate report, justifying the viability of the LCS technology, giving clear recommendations on the way forward and with an assessment of potential risks. Furthermore, the consultant will be expected to produce a brief debriefing note after the mission in Uganda.

4. Scope of work and activities

The scope of the assignment shall include but not necessarily be limited to the following:

- Assess the various low cost seal options under demonstration at MELTC and compare with the different options being applied in the region;
- Assess the viability of the various low cost seals options that have been demonstrated at MELTC;
- Assess the availability of materials for the various options including their flexibility towards alternative material use;
- Investigate adaptability to labour-based technology of the various options;
- Comment on the proposed training curriculum developed for training;

- Investigate maintenance needs and methodologies of the various options;
- Carry out cost benefit analysis of the different low cost seal options;
- Carry out life-cycle cost analysis of the different options;
- Investigate appropriate equipment requirements, including alternative options, for low cost seal technology and recommend the best modality and budget for their acquisition;
- Recommend an appropriate approach to be adopted for implementation of trial contracts on low cost seals at the districts;
- Provide a revised target of km of roads which can be sealed, considering the available time frame and funding levels;
- Assess the preferences of the MoWT in terms of all parameters and associated choice of LCS types.
- Assess and recommend the approach to be adopted for LCS implementation either as maintenance operations through the Road Fund or through dedicated funding for road rehabilitation and construction;
- Assess potential risks and assumptions related to the implementation of the LCS under RTI and recommend possible risk management and mitigation measures to be adopted;
- Assess to what extent the cross cutting issues have been considered during the demonstration in the development of the guidelines and training modules; and
- Assess the readiness (guidelines and specifications), sustainability of the LCS technology and recommend appropriate strategy to be adopted by the MoWT in order to promote the LCS technology in Uganda;
- Assess the sustainability of LCS in Uganda.

5. Methodology

The Consultant shall review all relevant documents including those prepared by the low cost seal consultant (TRL) and have a briefing meeting with the Embassy/MoWT at the commencement of the assignment. The Consultant shall hold some consultations to solicit views from the a cross section of stakeholders which include; the Ministry of Works and Transport; MELTC, UNRA, The Road Fund, the developments partners (Dfid, WB, EU, JICA AfDB), a sample of some local governments, consultants and contractors including potential equipment suppliers. The Consultant shall make a field visit to the demonstration site at Mbale and selected districts local governments and shall hold discussion with the field staff and the local government officials.

6. Timing and reporting

The assignment is expected to commence during the first week of August 2012 and it shall be carried out in a period of 3-4 weeks. The mission in Uganda shall be approximately 8 days commencing on the 6th August 2012. The final report shall be submitted by the 31st August 2012.

7. The required consultant

The Consultant shall have an advanced degree in Engineering, Transport Economics or related field with demonstrated experience in the use and application of low cost seals in Africa generally or East Africa in particular. Experience in the use of labour based methods is desirable and knowledge and experience in research will be an added advantage.

8. Services and facilities

Office space during day time shall be provided to the Consultant at MELTC. The Consultant shall be assisted in making arrangements for meetings, where necessary. The Consultant shall provide for his transport arrangements, welfare including local communications and accommodation.

9. References

The following documents shall be availed to the consultant at the start of the assignment:

- The RTI Component Description, September 2009
- Final Report for the consultant on the development of low-cost sealing of roads in Uganda, August 2011
- MoWT, Policy for Development and Strengthening the National Construction Industry, January 2010,
- The Uganda National Development Plan Final Report, April 2010.

ANNEX B – LIST OF PERSONS AND ORGANISATIONS MET

Monday 6th August 2012.

0900 – 1000 **Danish Embassy (Danida)**
Stephen J. Ajalu, Senior programme advisor - Infrastructure

1015 – 1215 **Ministry of Works and Transport (MoWT)**
Usama kayima, MoWT
Per Christiansen, MoWT/MELTC
Kisira Samuel, MoWT/MELTC
Stephen Kitorsa, MoWT
Stephen Ajalu, Danish Embassy (Danida)
Komatpch Henry, MoWT/MELTC
Fred Wobusings, MoWT/MELTC

1330 – 1430 **COWI limited, Uganda**
Eng. David Rogers – Samugooma, COWI
Usama Kayima, MoWT

Tuesday 7th August 2012.

0910 – 1010 **MoWT. Commissioner for Construction Standards and Quality Management.**
Eng. Dr. Fredrick M. Were – Higenyi
Mutemo Charles, Principal Environmental Officer
Usama Kayima, MoWT

1030 – 1120 **Uganda Road Fund**
Chris Ntegakarija, Technical Assistant
Henry Kayanda, A/Accountant
Usama Kayima, MoWT

1200 – 1515 **Visited Matugga – Semuto – Kapeeke – Road Trial using Innovative Techniques.**
Eng. David Rogers – Samugooma, COWI, Uganda
Usama Kayima, MoWT

1515 – 1845 **Travel to Mbale**

Wednesday 8th August 2012.

0900 – 1230 **Visited trial road sections at Mbale.**
Usama Kayima, MoWT
Number of people from MELTC accompanied who had been involved in the construction of the trials.

1230 – 1240 **At METLC for various topics discussions.**
Welcome by Principal Samuel Kisisa.
Usama Kayima, MoWT
Fredrice Wobusinge, METCL
Per Kristensen, METCL

1240 – 1850 **METLC, presentation of various topic, regarding trial construction and contractor trial training and budget**
Various presentations by METLC lectures/engineers (see appendix 4)

1850 – 1910 **Talks with Contractor attached to the training modules for LCS**
Morgen Enterprises, Limited.
Usama Kayima, MoWT

Thursday 9th August 2012.

1030 - 1830 **Visit to U-grows districts (Teso region, Kumi district and Lango Sub region)**
1030 – 1200 Travel to Kumi
1200 – 1220 Meeting at District office
Assistant District Engineer Marakd Benyamen and Senior, Assistant Engineer Ariong Franw,
Usama Kayima, MoWT
Lectures/Engineers from MELTC.
1220 – 1320 Field visit
1320 – 1540 Travel to Lira
1540 – 1610 Meeting at District office
Senior Ass. Engineer Apita Fred
Usama Kayima, MoWT
1610 – 1810 Field visit
1900 – 1930 Meeting with contractor Angichi Enterprices. MD Richard Abongo

Friday 10th August 2012.

0900 - 1830 **Visit to Gulu district**
0900 – 1030 Travel from Lira to Gulu
1030 – 1100 Meeting District office. District Engineer Andrew Olal, Ass. District Eng. Charles Bongomia
Usama Kayima, MoWT
1100 – 1240 Field visit
1240 – 1320 Wrap up meeting at District office
1320 – 1840 Travel to Kampala

Monday 13th August 2012-08-16

0815 – 0950 JICA. Ms. IIjima Masae, Project formulation advisor. Ms. Nanami Akiko, representative
Usama Kayima, MoWT

1100 – 1215	CrossRoads. Mr. DJ Entwistle
1230 – 1315	UNRA. Project manager Charles Naita Usama Kayima, MoWT
1400 – 1815	Wrap-up meeting at Ministry of Works and Transport. Attendance list: Usama Kayima, MoWT Per Kristiansen, MoWT/MELTC Kisara Samuel Stephen Kitsera, MoWT Stephen Ajalu, DANIDA Henry Komalchech, MoWT/MELTC Fred Wobusinga, MoWT/MELTC DJ Entwistle, CrossRoads Thomas Fleurine Sorensen, CONSIA Mike Pinard, Consultant Charles Overby, Consultant
1900 – 2030	CONSIA Consultant Thomas Fleurine Sorensen

ANNEX C – LIFE CYCLE COST ANALYSIS DETAILS

Cost of seals per sq/m2

Mark up 25 %

		Cost UGX per sq.m						
		Bitumen	Aggregate	Labour	Equipment	Cost	15 % Mark up	Total
Single sand seal, river sand		7380	234	693	166	8473	2118	10591
Single sand seal, crusher dust		8140	855	693	166	9854	2464	12318
Slurry seal		8800	855	693	453	10801	2700	13501
SSD		8440	1600	693	189	10922	2731	13653
SDD + sand seal using crusher dust		10180	2265	693	453	13591	3398	16989
SDD + sand seal using river sand		10180	1929	693	453	13255	3314	16569
DSD								24000
Inverted DSD	20% higher bit.cost than normal DSD							26500
Single Otta seal, screened natural gravel		8680	1792	693	378	11543	2886	14429
Single Otta seal, crushed aggregate		8680	2560	693	378	12311	3078	15389
Single Otta seal, screened aggregate + riversand		8680	2026	1386	567	12659	3165	15824
Single Otta seal, screened aggregate + crusher dust		8680	3660	1386	567	14293	3573	17866
Single Otta seal, crushed aggregate + river sand		16060	2794	1386	567	20807	5202	26009
Single Otta seal, crushed aggregate + crusher dust		16060	3415	1386	567	21428	5357	26785
Double Otta, screened natural gravel	(30% cheaper than crushed agg.)	17360	3584	1386	756	23086	5772	28858
Double Otta, crushed aggregate		17360	5120	1386	756	24622	6156	30778
Cape seal		16500	2455	1386	355	20696	5174	25870
Penetration macadam		19020	3947	1872	374	25213	6303	31516
CMA using crushed aggrgate		15480	3408	693	362	19943	4986	24929
CMA using natural gravel	(5% more bitumen than for crushed aggregate)	16254	2385	693	362	19694	4924	24618

Note: The red numbers are estimated figures.

LIFE - CYCLE COST ANALYSIS SINGLE AND DOUBLE SAND SEALS

Single Sand seal using river sand

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	4.02	1.000	4.02
		1			
2	Resealing	2	4.02	0.797	3.20
		3			
		4			
		5			
3	Resealing	6	4.02	0.507	2.04
		7			
		8			
		9			
4	Resealing	10	4.02	0.322	1.29
		11			
		12			
		13			
5	Resealing	14	4.02	0.205	0.82
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**11.38**

Year	12%
1	0.892
2	0.797
3	0.712
4	0.636
5	0.567
6	0.507
7	0.452
8	0.404
9	0.361
10	0.322
11	0.288
12	0.257
13	0.230
14	0.205
15	0.183

Double Sand seal using river sand

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	7.44	1.00	7.44
		1			
		2			
		3			
		4			
		5			
		6			
2	Resealing	7	4.02	0.452	1.82
		8			
		9			
		10			
		11			
		12			
3	Resealing	13	4.02	0.230	0.92
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**10.18**

Single Sand seal using crusher dust

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	4.68	1.000	4.68
		1			
2	Resealing	2	4.68	0.797	3.73
		3			
		4			
		5			
3	Resealing	6	4.68	0.507	2.37
		7			
		8			
		9			
4	Resealing	10	4.68	0.322	1.51
		11			
		12			
		13			
5	Resealing	14	4.68	0.205	0.96
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**13.25**

Year	12%
1	0.892
2	0.797
3	0.712
4	0.636
5	0.567
6	0.507
7	0.452
8	0.404
9	0.361
10	0.322
11	0.288
12	0.257
13	0.230
14	0.205
15	0.183

Double Sand seal using crusher dust

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	8.66	1.000	8.66
		1			
		2			
		3			
		4			
		5			
		6			
2	Resealing	7	4.68	0.452	2.12
		8			
		9			
		10			
		11			
		12			
3	Resealing	13	4.68	0.230	1.08
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**11.85**

LIFE - CYCLE COST ANALYSIS SINGLE AND DOUBLE SLURRY SEALS

Single slurry seal

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	5.13	1.00	5.13
		1			
2	Resealing	2	5.13	0.797	4.09
		3			
		4			
		5			
3	Resealing	6	5.13	0.507	2.60
		7			
		8			
		9			
4	Resealing	10	5.13	0.322	1.65
		11			
		12			
		13			
5	Resealing	14	5.13	0.205	1.05
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**14.52**

Year	12%
1	0.892
2	0.797
3	0.712
4	0.636
5	0.567
6	0.507
7	0.452
8	0.404
9	0.361
10	0.322
11	0.288
12	0.257
13	0.230
14	0.205
15	0.183

Double slurry seal

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	9.49	1.00	9.49
		1			
		2			
		3			
		4			
		5			
		6			
2	Resealing	7	5.13	0.452	2.32
		8			
		9			
		10			
		11			
		12			
3	Resealing	13	5.13	0.230	1.18
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**12.99**

LIFE - CYCLE COST ANALYSIS SINGLE SURFACE DRESSING + CAPPED RIVER SAND AND DOUBLE SURFACE DRESSING

Single Surface Dressing

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	5.19	1.000	5.19
		1			
2	Resealing (sand)	2	4.02	0.797	3.20
		3			
		4			
		5			
3	Resealing (sand)	6	4.02	0.507	2.04
		7			
		8			
		9			
4	Resealing (6,7 mm)	10	5.19	0.322	1.67
		11			
		12			
5	Resealing (sand)	13	4.02	0.230	0.92
		14			
		15			
				TOTAL (US$)	**13.03**

Year	12%
1	0.892
2	0.797
3	0.712
4	0.636
5	0.567
6	0.507
7	0.452
8	0.404
9	0.361
10	0.322
11	0.288
12	0.257
13	0.230
14	0.205
15	0.183

Single Surface Dressing capped with river sand

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	6.30	1.000	6.30
		1			
		2			
		3			
		4			
2	Resealing 6,7 mm	5	5.19	0.567	2.94
		6			
		7			
		8			
		9			
3	Resealing (sand)	10	4.02	0.322	1.29
		11			
		12			
		13			
4	Resealing 13,2 mm	14	5.19	0.205	1.06
		15			
				TOTAL (US$)	**11.60**

Year	12%
1	0.892
2	0.797
3	0.712
4	0.636
5	0.567
6	0.507
7	0.452
8	0.404
9	0.361
10	0.322
11	0.288
12	0.257
13	0.230
14	0.205
15	0.183

Single Surface Dressing capped with crusher dust

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	6.46	1.000	6.46
		1			
		2			
		3			
		4			
2	Resealing 6,7 mm	5	5.19	0.567	2.94
		6			
		7			
		8			
		9			
3	Resealing (sand)	10	4.68	0.322	1.51
		11			
		12			
		13			
4	Resealing 13,2 mm	14	5.19	0.205	1.06
		15			
				TOTAL (US$)	**11.97**

LIFE - CYCLE COST ANALYSIS SINGLE SURFACE DRESSING + CAPPED RIVER SAND AND DOUBLE SURFACE DRESSING

Single Surface Dressing

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	5.19	1.000	5.19
		1			
2	Resealing (sand)	2	4.02	0.797	3.20
		3			
		4			
		5			
3	Resealing (sand)	6	4.02	0.507	2.04
		7			
		8			
		9			
4	Resealing (6,7 mm)	10	5.19	0.322	1.67
		11			
		12			
5	Resealing (sand)	13	4.02	0.230	0.92
		14			
		15			
				TOTAL (US$)	13.03

Year	12%
1	0.892
2	0.797
3	0.712
4	0.636
5	0.567
6	0.507
7	0.452
8	0.404
9	0.361
10	0.322
11	0.288
12	0.257
13	0.230
14	0.205
15	0.183

Single Surface Dressing capped with river sand

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	6.30	1.000	6.30
		1			
		2			
		3			
		4			
2	Resealing 6,7 mm	5	5.19	0.567	2.94
		6			
		7			
		8			
		9			
3	Resealing (sand)	10	4.02	0.322	1.29
		11			
		12			
		13			
4	Resealing 13,2 mm	14	5.19	0.205	1.06
		15			
				TOTAL (US$)	11.60

Year	12%
1	0.892
2	0.797
3	0.712
4	0.636
5	0.567
6	0.507
7	0.452
8	0.404
9	0.361
10	0.322
11	0.288
12	0.257
13	0.230
14	0.205
15	0.183

Single Surface Dressing capped with crusher dust

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	6.46	1.000	6.46
		1			
		2			
		3			
		4			
2	Resealing 6,7 mm	5	5.19	0.567	2.94
		6			
		7			
		8			
		9			
3	Resealing (sand)	10	4.68	0.322	1.51
		11			
		12			
		13			
4	Resealing 13,2 mm	14	5.19	0.205	1.06
		15			
				TOTAL (US$)	11.97

Double Surface Dressing 13,2 + 6,7 mm

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	9.60	1.000	9.60
		1			
		2			
		3			
		4			
		5			
		6			
2	Sand capping river sand	7	4,02	0.452	1.81704
		8			
		9			
		10			
		11			
		12			
3	Resealing 6,7 mm	13	5.19	0.230	1.19
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**12.61**

Inverted Double Surface Dressing 19,0 mm + 13,2 mm

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	11.52	1.000	11.52
		1			
		2			
		3			
		4			
		5			
		6			
		7			
2	Resealing 6,7 mm	8	5.19	0.404	2.10
		9			
		10			
		11			
		12			
		13			
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**13.62**

Year	12%
1	0.892
2	0.797
3	0.712
4	0.636
5	0.567
6	0.507
7	0.452
8	0.404
9	0.361
10	0.322
11	0.288
12	0.257
13	0.230
14	0.205
15	0.183

LIFE - CYCLE COST ANALYSIS SINGLE AND DOUBLE SAND SEALS

Single Sand seal using river sand

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	4.02	1.000	4.02
		1			
2	Resealing	2	4.02	0.797	3.20
		3			
		4			
		5			
3	Resealing	6	4.02	0.507	2.04
		7			
		8			
		9			
4	Resealing	10	4.02	0.322	1.29
		11			
		12			
		13			
5	Resealing	14	4.02	0.205	0.82
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**11.38**

Year	12%
1	0.892
2	0.797
3	0.712
4	0.636
5	0.567
6	0.507
7	0.452
8	0.404
9	0.361
10	0.322
11	0.288
12	0.257
13	0.230
14	0.205
15	0.183

Double Sand seal using river sand

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	7.44	1.00	7.44
		1			
		2			
		3			
		4			
		5			
		6			
2	Resealing	7	4.02	0.452	1.82
		8			
		9			
		10			
		11			
		12			
3	Resealing	13	4.02	0.230	0.92
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**10.18**

Single Sand seal using crusher dust

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	4.68	1.000	4.68
		1			
2	Resealing	2	4.68	0.797	3.73
		3			
		4			
		5			
3	Resealing	6	4.68	0.507	2.37
		7			
		8			
		9			
4	Resealing	10	4.68	0.322	1.51
		11			
		12			
		13			
5	Resealing	14	4.68	0.205	0.96
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**13.25**

Year	12%
1	0.892
2	0.797
3	0.712
4	0.636
5	0.567
6	0.507
7	0.452
8	0.404
9	0.361
10	0.322
11	0.288
12	0.257
13	0.230
14	0.205
15	0.183

Double Sand seal using crusher dust

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	8.66	1.000	8.66
		1			
		2			
		3			
		4			
		5			
		6			
2	Resealing	7	4.68	0.452	2.12
		8			
		9			
		10			
		11			
		12			
3	Resealing	13	4.68	0.230	1.08
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**11.85**

LIFE - CYCLE COST ANALYSIS OTTA SEALS

Single Otta seal, screened natural gravel

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	5.48	1.00	5.48
		1			
		2			
2	Resealing Otta seal	3	5.48	0.71	3.90
		4			
		5			
		6			
		7			
3	Resealing river sand	8	4.02	0.404	1.62
		9			
		10			
		11			
		12			
4	Resealing Otta seal	13	5.48	0.230	1.26
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**12.27**

Single Otta seal, crushed aggregate

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	5.85	1.00	5.85
		1			
		2			
2	Resealing Otta seal	3	5.85	0.71	4.17
		4			
		5			
		6			
		7			
3	Resealing river sand	8	4.02	0.404	1.62
		9			
		10			
		11			
		12			
4	Resealing Otta seal	13	5.85	0.230	1.35
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**12.98**

Single Otta seal, screened natural gravel with river sand cover seal

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	8.90	1.00	8.90
		1			
		2			
		3			
		4			
		5			
		6			
		7			
		8			
2	Resealing	9	5.48	0.36	1.98
		10			
		11			
		12			
		13			
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**10.88**

Single Otta seal, crushed aggregate with crusher dust cover seal

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	9.83	1.00	9.83
		1			
		2			
		3			
		4			
		5			
		6			
		7			
		8			
2	Resealing	9	5.85	0.36	2.11
		10			
		11			
		12			
		13			
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**11.94**

Double Otta seal, screened natural gravel

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	10.14	1.00	10.14
		1			
		2			
		3			
		4			
		5			
		6			
		7			
		8			
		9			
		10			
		11			
		12			
		13			
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**10.14**

Double Otta seal, crushed aggregate

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	10.82	1.00	10.82
		1			
		2			
		3			
		4			
		5			
		6			
		7			
		8			
		9			
		10			
		11			
		12			
		13			
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**10.82**

LIFE - CYCLE COST ANALYSIS CAPE SEAL

Cape seal (16 mm + slurry)

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	9.55	1.00	9.55
		1			
		2			
		3			
		4			
		5			
		6			
		7			
		8			
		9			
1	Resealing with slurry	10	5.13	0.322	1.65
		11			
		12			
		13			
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**11.20**

Year	12%
1	0.892
2	0.797
3	0.712
4	0.636
5	0.567
6	0.507
7	0.452
8	0.404
9	0.361
10	0.322
11	0.288
12	0.257
13	0.23
14	0.205
15	0.183

LIFE - CYCLE COST ANALYSIS PENETRATION MACADAM (20 - 40 MM) + SURFACE DRESSING 13,2 MM
Penetration Macadam (20 - 40 mm) + 13,2 mm key stone

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	11.98	1.00	11.98
		1			
		2			
		3			
		4			
		5			
1	Sand capping, river sand	6	4.02	0.51	2.04
		7			
		8			
		9			
		10			
		11			
		12			
		13			
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**14.02**

Year	12%
1	0.892
2	0.797
3	0.712
4	0.636
5	0.567
6	0.507
7	0.452
8	0.404
9	0.361
10	0.322
11	0.288
12	0.257
13	0.23
14	0.205
15	0.183

LIFE - CYCLE COST ANALYSIS COLD MIX ASPHALT USING CRUSHED AGGREGATE

Cold mix asphalt (CMA) using crushed aggrgate

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	9.47	1.00	9.47
		1			
		2			
		3			
		4			
		5			
,		6			
		7			
1	New CMA	8	9.47	0.40	3.83
		9			
		10			
		11			
		12			
		13			
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**13.30**

Year	12%
1	0.892
2	0.797
3	0.712
4	0.636
5	0.567
6	0.507
7	0.452
8	0.404
9	0.361
10	0.322
11	0.288
12	0.257
13	0.23
14	0.205
15	0.183

Cold mix asphalt (CMA) using screened natural gravel

Activity no	Activity item	Years after construction	2012 Base Cost/m2 (US$)	12% Discount Factor	NPV of Cost/m2 (US$)
1	Construct surfacing	0	9.35	1.00	9.35
		1			
		2			
		3			
		4			
		5			
,		6			
		7			
1	New CMA	8	9.35	0.40	3.78
		9			
		10			
		11			
		12			
		13			
		14			
		15			
	Assume life span of 15 years.			**TOTAL (US$)**	**13.13**

Life cycle cost analysis		NPV of Cost/m2 (US$)	Rating
Single sand seal, river sand		11.38	6
Single sand seal, crusher dust		13.25	17
Double sand seal, river sand		10.18	2
Double sand seal, crusher dust		11.85	8
Single Slurry seal		14.52	22
Double slurry		12.99	14
SSD		13.03	15
SDD + sand seal using crusher dust		11.97	9
SDD + sand seal using river sand		11.60	7
DSD		#VALUE!	12
Inverted DSD	20% higher bit.cost than normal DSD	13.62	19
Single Otta seal, screened natural gravel		12.27	11
Single Otta seal, crushed aggregate		12.98	13
Single Otta seal, screened aggregate + riversand		10.88	4
Single Otta seal, screened aggregate + crusher dust		11.94	10
Double Otta, screened natural gravel	(30% cheaper than crushed agg.)	10.14	1
Double Otta, crushed aggregate		10.82	3
Cape seal		11.20	5
Penetration macadam		14.02	20
CMA using crushed aggrgate		13.30	18
CMA using natural gravel	(5% more bitumen than for crushed aggregate)	13.13	16

Option No.	LCS Option Type	Construction Cost (US$/m^2)	Life cycle cost (US$/m^2)	Cost-effective-ness rating
16	Double Otta seal (screened natural gravel)	10.97	10.14	1
3	Double sand seal (river sand)	7.44	10.18	2
17	Double Otta seal (crushed aggregate)	11.70	10.82	3
14	Single Otta seal (screened gravel) + river sand seal	9.88	10.88	4
18	Cape Seal	9.83	11.20	5
1	Single sand seal (river sand)	4.02	11.38	6
8	Single Surface Dressing + sand seal (river sand)	6.30	11.60	7
4	Double sand seal (crusher dust)	8.66	11.85	8
15	Single Otta seal (screened gravel) + crusher dust	10.48	11.94	9
9	Single Surface Dressing + sand seal (crusher dust)	6.46	11.97	10
12	Single Otta seal (screened natural gravel)	5.48	12.27	11
10	Double surface dressing	9.12	12.61	12
13	Single Otta seal (crushed aggregate)	5.85	12.98	13
6	Double slurry seal	9.49	12.99	14
7	Single surface dressing (SSD)	5.19	13.03	15
21	Cold mix asphalt (crushed aggregate)	9.47	13.13	16
2	Single sand seal (crusher dust)	4.68	13.25	17
20	Cold Mix Asphalt (screened natural gravel)	9.35	13.30	18
11	Inverted double surface dressing	10.07	13.62	19
19	Penetration Macadam	11.98	14.02	20
5	Single slurry seal	5.13	14.52	21