Bituminous surfacings for low volume roads and temporary deviations

Manual 10 May 2012

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Manual 10

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Manuals published by Sabita

Manual 1	Construction of bitumen rubber seals
Manual 2	Bituminous binders for road construction and maintenance (CD)
Manual 3*	Test methods for bitumen rubber
Manual 4*	Specifications for rubber in binders
Manual 5	Manufacture and construction of hot mix asphalt
Manual 6*	Interim specifications for bitumen rubber
Manual 7	SuperSurf: Economic warrants for surfacing unpaved roads
Manual 8	Safe and responsible handling of bituminous products (CD)
Manual 9****	Bituminous surfacings for temporary deviations
Manual 10	Bituminous surfacings for low volume roads and temporary deviations (CD)
Manual 11	Labour enhanced construction for bituminous surfacings
Manual 12	Methods for labour enhanced construction for bituminous surfacings (CD)
Manual 13	LAMBS - The design and use of large aggregate mixes for bases
Manual 14***	GEMS - The design and use of granular emulsion mixes
Manual 15*	Technical guidelines for seals using homogeneous modified binders
Manual 16**	REACT - Economic analysis of short-term rehabilitation actions
Manual 17	The design and use of porous asphalt mixes (CD)
Manual 18	Appropriate standards for the use of sand asphalt
Manual 19	Guidelines for the design, manufacture and construction of bitumen-rubber asphalt wearing courses
Manual 20	Sealing of active cracks in road pavements
Manual 21***	ETB: The design and use of emulsion treated bases
Manual 22	Hot mix paving in adverse weather
Manual 23	Code of Practice: Loading bitumen at refineries (CD)
Manual 24	User guide for the design of hot mix asphalt
Manual 25	Quality management in the handling and transport of bituminous binders
Manual 26	Interim guidelines for primes and stone precoating fluids (CD)
Manual 27	Guideline for thin layer hot mix asphalt wearing courses on residential streets
Manual 28	Best practice for the design and construction of slurry seals (CD)
Manual 29	Guide to the safe handling of solvents in a bituminous products laboratory (CD)
Manual 30	A guide to the selection of bituminous binders for road construction (CD)
Manual 31	Guidelines for calibrating a binder distributor and ensuring satisfactory performance (CD)
Manual 32	Best practice guideline for warm mix asphalt (CD)

* These manuals have been withdrawn and their contents have been incorporated in Technical Guideline 1 (see below).

** This manual has been withdrawn and its software programme incorporated in TRH12: *Flexible pavement rehabilitation investigation and design.*

*** These manuals have been withdrawn and their contents have been incorporated in Technical Guideline 2 (see below).

**** This manual has been withdrawn and its contents have been incorporated in the second edition of Manual 10.

Technical guidelines

TG1	The use of modified binders in road construction
TG2	Bitumen stabilised materials
TG3	Asphalt reinforcement for road construction

Sabita DVD Series

DVD100 **Testing of bituminous products**

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M van Eeden
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Introduction

1.1 Background

The provision of all-weather access to both rural and urban communities is a government priority in support of the overarching aim of poverty alleviation and stimulation of economic growth.

Sabita Manual 10: *Appropriate standards for bituminous surfacings*, was first published in May 1992. While the principles in the original manual are still relevant to current realities, certain aspects are now outdated and/or not properly addressed.

The revision of Manual 10 provides a guideline for both the surfacing and maintenance of low volume roads as an aid for both technical and non-technical (managerial) personnel involved in decision-making related to the provision of all-weather access to rural and urban communities.

The main focus of the manual is to provide important information for the upgrading and maintenance of low volume surfaced roads, and to guide practitioners in the selection of an appropriate bituminous surfacing for different conditions.

Due to the similarities for selection of bituminous surfacings being considered, guidance is also provided for temporary deviations during road construction. Therefore, this document also replaces Sabita Manual 9: *Bituminous surfacings for temporary deviations.*

1.2 Source information

Information and guidelines provided in this document are based on the initial findings of a Sabita-sponsored research project (*Appropriate standards for effective bituminous seals*) leading to the publication of Sabita manuals 9 and 10 (1992), recent literature surveys, communication with practitioners in southern Africa, and on-going experience and performance assessment of various bituminous surfacings in the region. A workshop during the Conference for Asphalt Pavements in Southern Africa, CAPSA'11, clarified several uncertainties.

1.3 Scope

This document first examines the background history associated with surfacing unsealed roads, highlighting the main considerations and benefits for such an investment.

Emphasis is then placed on the selection of appropriate bituminous surfacing types and binders for different situations, followed by some recommendations where relaxation of existing standards could be considered.

To assist with the selection of an appropriate surfacing for a particular application, typical unit costs of different surfacing types are then provided and the need for and impact of maintenance strategies discussed.

Finally, cost components required for economic evaluation are provided and available software discussed to assist practitioners in quantifying warrants for upgrading.

Examples of various surfacing types and performance ratings by practitioners are given in Appendix A.

2 Surfacing of unsealed roads

2.1 Main considerations

2.1.1 General

The surfacing of low volume roads could be motivated by various reasons such as:

- Economic viability;
- Social reasons; and
- Environmental considerations.

2.1.2 Economic viability

Upgrading of a road to a surfaced standard is economically viable when the quantifiable benefits exceed the cost of construction and maintenance. The differences in costs and benefits of competing surfacing options over a chosen analysis period is discounted to the Net Present Value (today's cost) and compared.

As discussed in Chapter 7, not all benefits are easily quantified and have, in the past, often been ignored.

Figure 1 displays the main cost components that should be taken into account during economic evaluation. Although not to scale in the figure, the benefits resulting from savings in vehicle operating costs due to the smoother ride often overrides all other costs. Therefore, the higher the traffic volume and the poorer the level to which the unsealed road is maintained (riding quality), the higher the return on the upgrading investment.

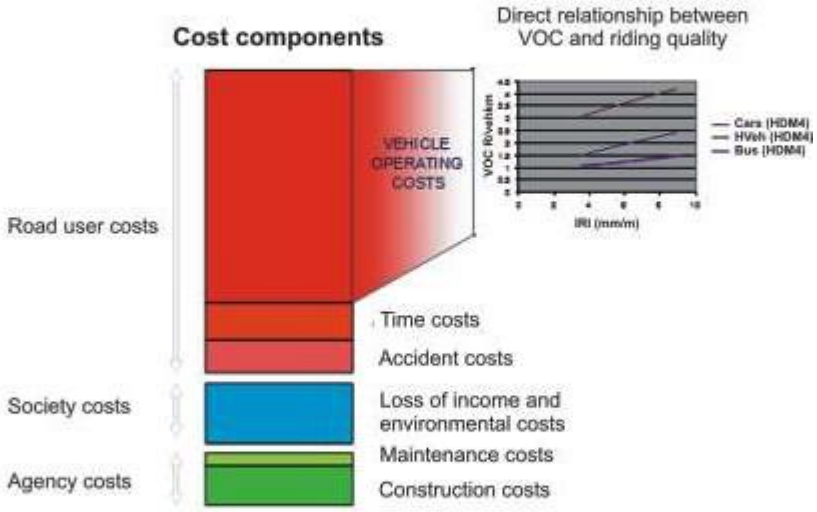


Figure 1: Main cost components for economic analysis

Note

Financial viability only takes into account the costs and savings to the road authority itself. Therefore, if the cost to provide and maintain the surfaced alternative is cheaper than to maintain the gravel alternative, the project is financially viable to the authority.

2.1.3 Social

The purpose of road improvement could be motivated to improve the quality of living, to create employment opportunities or development spin-offs to the affected communities.

The majority of social benefits are difficult to quantify in monetary terms. Therefore, it is often recommended that these are incorporated in a multi criteria analysis as explained in Section 7.6.

2.1.4 Environmental

The main environmental benefits obtained through surfacing the road are:

- Protection of rare fauna and flora;
- Less dust pollution with its negative impact on health and produce;
- Reduced pollution of water courses;
- Protection of scarce materials that meet G4 to G6 requirements.

A strategy could be followed to surface the road to conserve scarce good materials such as G4 - G6 gravels for use in later construction and upgrading. As with the case of social benefits, the benefits are often difficult to quantify, requiring incorporation in a multi criteria analysis.

It is believed that more research into the effect of road dust on health and agricultural crop production could assist to quantify the benefits towards surfacing of roads.

2.1.5 Government directives

Government, at different levels, could dictate particular activities such as the surfacing of a road for political reasons. However, cognisance should be taken of long term, national strategic plans, and decisions taken at this level should be aligned to the country's strategy for economic development, social upliftment requirements and environmental requirements.

2.1.6 Closing the quality gap in service provision

Public opinion indicates a huge gap in the quality of service provided by road authorities (Figure 2), creating major conflict in terms of *"Why can they have a surfaced road and not us?"* Surfacing of low volume roads to appropriate standards is a sustainable practice and provides a more continuous quality of service.

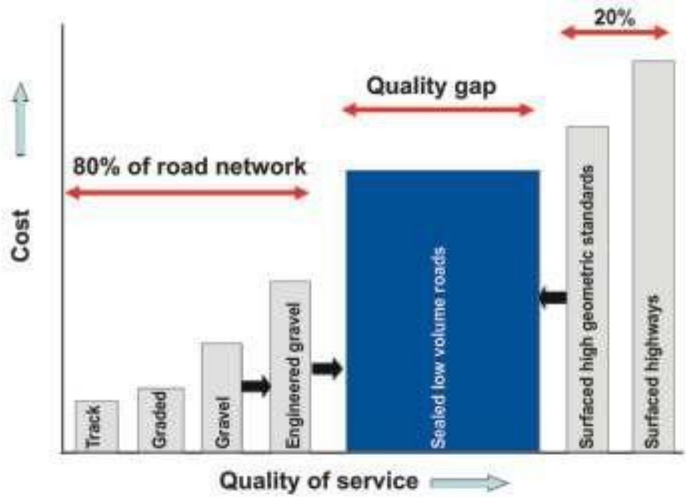


Figure 2: Public perception of service quality

2.2 Level and standards of upgrading

2.2.1 Appropriate standards

The cost of providing a low volume surfaced road is dependent on:

- The standard of the existing facility/road;
- The required geometric standard in terms of cross section and alignment;
- Cross drainage structures (bridges) required to ensure passability;
- Pavement structure; and
- Bituminous surfacing type.

As the focus of this manual is on the selection of an appropriate bituminous surfacing, appropriate standards for pavement design, bridges and road geometry are not discussed in detail. Relevant information on these topics can be obtained from the following documentation:

- TRH4 (1996);
- TRH20 (2008);
- AASHTO *Guidelines for geometric design of very low-volume local roads* (ADT <400);

- Department of Transport document RR 92/466/2 - *Guidelines for upgrading of low volume rural roads*;
- SATCC/SADC Low volume sealed roads manual, 2003;
- ARRB Research Report ARR 354: *Road classifications, geometric designs and maintenance for low volume roads*, 2001.

Several concerns have been raised by industry regarding the poor performance of low volume surfaced roads, often blaming the bituminous surfacing, while the cause of failures were actually related to:

- Poor drainage;
- Insufficient structural capacity;
- Poor construction; and
- Poor maintenance.

Therefore, it is considered essential to highlight these risks and to provide some guidelines to optimise the investment return achieved by application of a bituminous surfacing, while minimising the risk.

2.3 Principles of pavement performance

2.3.1 Pavement structural capacity

Road pavements are designed to carry traffic for a specific design period without excessive deformation and/or failure due to fatigue.

As discussed further in the document, the appropriate initial seal should have a service life in the order of ten years. Therefore, the total pavement structure should be strong enough to carry the traffic load for a period of at least ten years.

2.3.2 Drainage

The presence of moisture reduces the strength of the pavement layers as well as the support strength of the *in-situ* subgrade. Therefore, to optimise the performance of the road pavement, the pavement layers should be elevated above the natural ground level or, as far as possible, above the side drain invert level. From previous studies (Emery, 1985 and 1992), it is assumed that the natural moisture conditions in the subgrade differ according to the macro-climatic environment as defined by Weinert (1980).

Although the ideal would be to specify the final road level relative to the natural ground level, provision and maintenance of side drains could, to a large extent, reduce the moisture content in the pavement structure. Therefore, for the purposes of this document and to minimise costs, the target final road level is recommended relative to the drain invert level (h_{min}). It is further recommended that the top of the road bed formation/fill/selected layer (d_{min}) should be at least 150 mm above the natural ground level as shown in Figure 3.

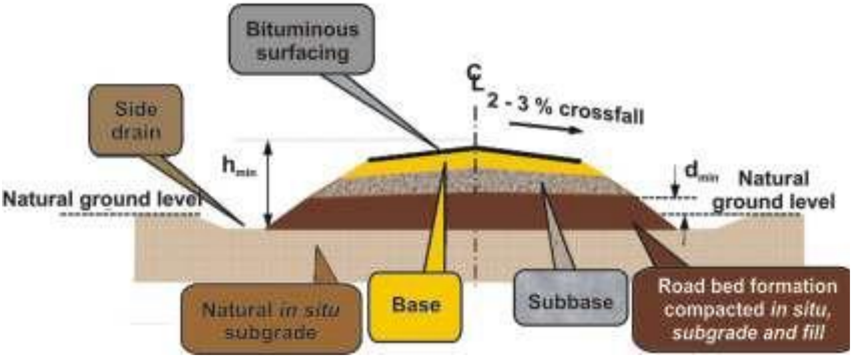


Figure 3: Road pavement cross section

Table 1 shows the recommended final road level above the side drain invert level for different traffic classes and macro-climatic environments.

Table 1 : Recommended final road level above drain invert

Traffic class grouping	Approx. AADT with 10% heavy vehicles (both directions)	Height above drain invert level (h_{min})		
		Dry climate (Weinert N>5)	Mod. climate (Weinert N 2-5)	Wet climate (Weinert N<2)
ES 0,003 - ES 0,01	< 200	250	300	350
ES 0,03 - ES 0,1	200 - 400	350	400	450
ES 0,01 - ES 0,30	> 400	450	500	550

2.3.3 Maintenance

Regular routine maintenance and periodic maintenance (reseal) reduces the risk of moisture ingress into the pavement structural layers. The need and planning for maintenance is further discussed in Chapter 6.

3 Bituminous surfacings

3.1 Definitions of surfacing types

3.1.1 General

Terminology for different surfacing types varies for different countries and even within the local region. For purposes of this manual, Figure 4 highlights the different bituminous surfacing types and their terminology.

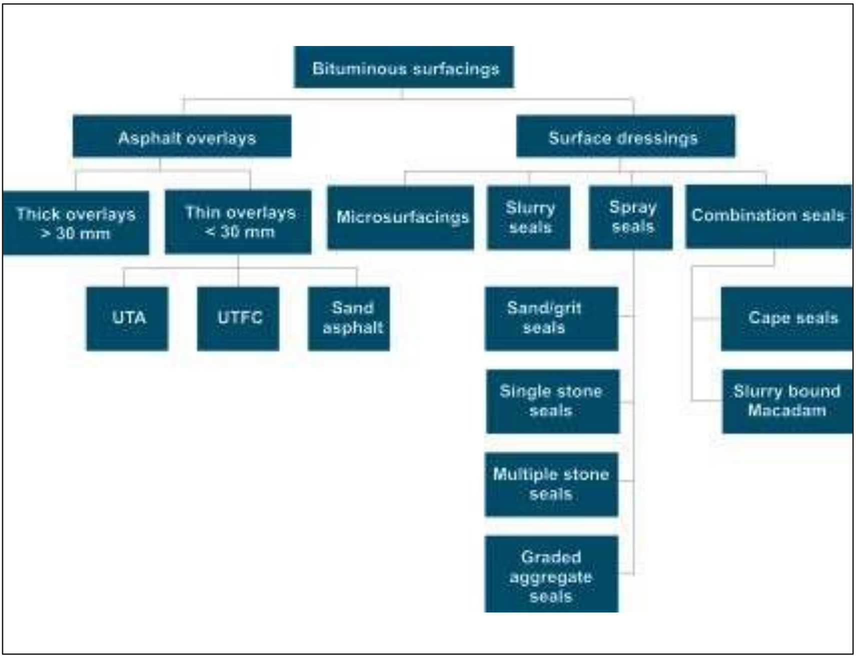


Figure 4: Bituminous surfacing types

3.1.2 Asphalt overlays

Asphalt overlay types could be defined in different ways (e.g. by a description of the grading). For the purposes of this manual, distinction is made between thick and thin overlays.

Thick and thin hot mixes used for low volume roads are mainly continuous graded mixes. Ultra Thin Asphalt (UTA) in the order of 12 mm has been used on low volume roads in certain parts of South Africa with success (refer to Sabita Manual 27: *Guideline for hot mix asphalt wearing courses on residential streets*).

Ultra Thin Friction Course (UTFC) is not used on low volume roads, but is included under the category *thin overlays* in Figure 4 as a result of its typical thickness of 15 mm - 20 mm.

Although sand asphalt has been used in South Africa on low volume roads for a long time and well described in local documentation[1], it appears as if the use of this surfacing type is not favoured by current practitioners.

A further distinction could be made regarding the temperature of application, as this affects the use in remote areas related to constructability and performance. The different categories of overlays are:

- Hot mix asphalt (HMA);
- Warm mix asphalt (WMA); and
- Cold mix asphalt (CMA).

3.1.3 Surface dressings

Surface dressings are mainly used on low volume roads in southern Africa and can be categorised as microsurfacings, slurries, sprayed seals and combination seals.

- **Microsurfacings and slurry seals:** Slurry is a homogeneous mixture consisting of:
    - Fine aggregate (normally crusher dust) or, where required to satisfy grading requirements and permitted, a blend of crusher dust and a limited percentage of approved natural sand;
    - Stable grade bitumen emulsion (anionic or cationic) or a polymer modified stable grade emulsion;
    - Filler (usually cement or lime);
    - Water;
    - Additive to retard the setting rate (in case of rapid setting slurry or microsurfacings);
    - Polymer (in case of microsurfacings).

Anionic stable grade emulsions are normally used for conventional slurries. The lack of attraction between the bitumen and the aggregate dictates that curing (breaking) occurs only as a result of normal water evaporation, making the conventional slurry highly suitable for labour intensive surfacings. However, as a consequence of the slow setting time, conventional slurries are often not appropriate for use in the urban environment.

Special cationic emulsions that contain no polymers are used for rapid setting slurry mixtures. Curing (breaking) occurs as a result of normal water evaporation. However, the speed of curing is increased due to the stronger attraction between the positively charged binder and the negatively charged aggregate, and the action of cement that upsets the pH balance of the acidic emulsion.

Microsurfacings consist of aggregate, cationic emulsion, latex (polymer) and additional chemicals to control the speed of curing (breaking). A stronger adhesion between the binder and the aggregate is facilitated through the addition of a polymer. Microsurfacings are appropriate for application in poor weather conditions when traffic has to be accommodated soon after construction, or if a thick layer is required (e.g. up to 30mm).

Note

Microsurfacings and rapid setting slurries are not suitable for labour intensive construction.

- **Sprayed seals**: Sprayed seals are constructed by spraying bituminous binder, spreading a layer of aggregate and rolling. For the purpose of this document sprayed seals are categorised as:
    - Sand/grit seals;
    - Single stone seals (including single stone and sand blinding layer);
    - Multiple stone seals (double or triple stone seals);
    - Graded aggregate seals (e.g. Otta seals).
- **Combination seals:** These seals are seal types consisting of at least two components with different characteristics, e.g.:
    - Cape seals which is a single stone seal with one or two layers of slurry);
    - Slurry-bound Macadam seal, consisting of a multiple layer of single-sized stone with a fine slurry vibrated into the voids.

3.2 Prime coat need and selection

A "prime" or "prime coat", according to guideline documents, e.g. Sabita Manual 26 (*Interim guidelines for primes and stone pre-coating fluids)* is defined as "a coat of suitable bituminous binder applied to a non-bituminous granular pavement layer as a preliminary treatment prior to the application of a bituminous base or surfacing".

It is further stated that the function of the prime is to penetrate the layer to which it is applied while leaving a small residual amount of binder on the surface to:

- Assist in promoting adhesion between the base and the newly applied bituminous surfacing or layer;
- Inhibit the ingress of water from rain into the base while not hampering the migration of water in the vapour phase out of the base;
- Limit the absorption of binder from the next spray application into the base; and
- Bind the finer particles on the upper zone of the base to accommodate light construction traffic for a short period until the new surfacing can be placed.

Distinction should be made between a prime coat, a tack coat (before asphalt applications) and a curing membrane (specifically applied on stabilised bases) to minimise moisture evaporation.

Notes

- Numerous cases have been recorded where prime coats have been omitted with success. The key to good surfacing performance stated in these cases is a properly compacted base, shiny in appearance and without any loose material.
- It is often stated that a prime coat is not required when:
    - The granular base is foam or emulsion treated and slushed with diluted emulsion;
    - Spraying cut-back bitumen (MC3000 or MC800) or high cutter content dust palliatives.

However, several cases have been observed where these products penetrated too much leaving insufficient binder to hold the aggregate.

- TRH3 discusses treatment of the upper 10 - 20 mm of a granular base to accommodate traffic before surfacing as follows:

Notes (continued)

- On completion of the normal compaction and just before the final level is cut, the "mulch" of 25 mm of loose material on the surface is sprayed with a diluted emulsion. Stable grade anionic emulsion is diluted with 10 parts of water to 1 part emulsion. The loose material is moved by grader in small windrows across the road surface and back, with the pneumatic roller following in tandem. The surface is kept continuously "wet" with the diluted emulsion until a smooth compact surface is obtained, free of ruts or holes caused by the cutting of final levels;
- The road can be opened to slow-moving traffic as soon as final rolling has been completed and when the surface has been allowed to dry for 1 hour. After a day or two, depending on the condition of the base surface, a final spray of the 1 - 10 diluted emulsion can be applied to the road. The road can be left open to traffic until a sufficient length of road has been completed to accommodate a full tank load of bitumen for the application of the final spray;
- The advantages of this process are that there will be no areas of uncompacted material in ruts or holes and that it is a relatively easy operation. Small irregularities can be rectified during this period with hand-mixed materials of the same composition as that used for the finish.

Although this treatment is generally successful for this purpose and to omit the prime coat, cases have been mentioned of a biscuit layer being formed and delamination of this layer with time.

Based on experience in southern Africa, it is recommended that a prime coat is applied on all granular bases before construction of the bituminous surfacing. Although more costly than omitting it, it has the added benefit of showing deficiencies in the base, which can be corrected before construction of the surfacing.

For purposes of selecting the appropriate binder for the prime coat, the reader is referred to Sabita Manual 26[2].

3.3 New construction surfacing selection

3.3.1 Considerations

Expected surfacing lives: Practitioners often request that the expected surfacing life, life-cycle strategies and cost to calculate the cost-effectiveness of different seal and binder types are provided.
Much information has been published in the past regarding the service life of different surfacing types. However, very little information is provided

regarding the terminal condition, the mode of failure or why the road has been resealed, e.g.:

- Seal life is mostly based on time-of-reseal information obtained from pavement management systems, categorised per surfacing type from construction to remedial action. The reasons for reseal or remedial action (e.g. application of rejuvenator) are not stated. In several cases, the road is resealed based on structural cracking being reflected through the seal, while in other cases timeous resealing of the road was prevented due to a lack of funds;
- Cases of poor design and/or poor construction result in early remedial actions and reduced recorded life;
- The service life of an initial construction seal vs a reseal could be completely different;
- Sand seals, texture slurry seals and rejuvenating sprays form part of the existing seal;
- Some tables showing expected service lives have been compiled from gut feel from practitioners without stating the reasons, assumptions and rationale behind the figures.

Oliver[3] developed a model for the hardening of the bituminous binder with the following factors playing the most important role:

- Temperature of the bitumen (throughout the seal life);
- Reactivity of the bitumen (durability); and
- Binder film thickness.

Later publications[4] provide a revised model to include risk factors, which are based on the influence of moisture ingress and damage to the pavement structure. It is further acknowledged that:

- High binder content seals did not form part of the investigation;
- Rejuvenation treatments will extend pavement life;
- Only conventional binders were evaluated;
- Only sprayed seals (chip seals/stone seals were investigated).

Based on the above it is concluded that:

- Figures published are not necessarily relevant for purposes of comparing the total range of possible seal and binder types. Therefore, the emphasis in this document is placed on the selection of effective surfacings for different conditions and not on cost-effectiveness;

- Properly constructed multiple seals, combinations seals and asphalt surfacings on properly constructed base layers, should last for at least a period of 10 years on low volume roads.

Purpose and life-cycle strategy: The deemed purpose of the surfacing, and the life-cycle strategy selected, could assist in the selection of the initial construction surfacing.

Asphalt, multiple stone seals, thick microsurfacings, thick graded aggregate seals and combination seals should give a service life of at least ten years before resurfacing is required.

Note

Depending on the design, construction and environment, multiple stone seals might require an additional fogspray within the 10-year period.

The initial cost of a sand seal, single seal, thin slurry or thin graded seal could be much less, making such a selection attractive. However, experience indicates that these surfacing types mostly require a reseal or rejuvenation (single seals) within a few years of construction, after which the total surfacing layer could perform well for the rest of the ten-year period.

Typical optimistic life-cycle strategies are shown in figures 5 - 11. The type of reseal is dependent on the condition of the road at that time. What is important, however, is to understand that the selection of specific types of initial surfacings will most probably require some intervention within a relative short period. Not planning for such interventions could result in rapid deterioration of the surfacing itself and the pavement structure.

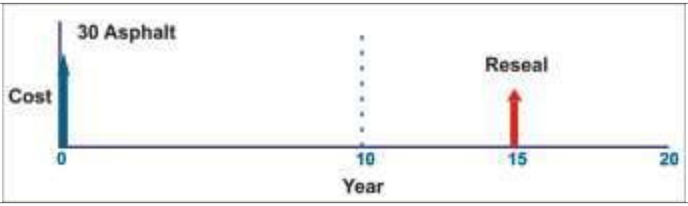


Figure 5 : Typical life-cycle strategy - 30 mm asphalt surfacing

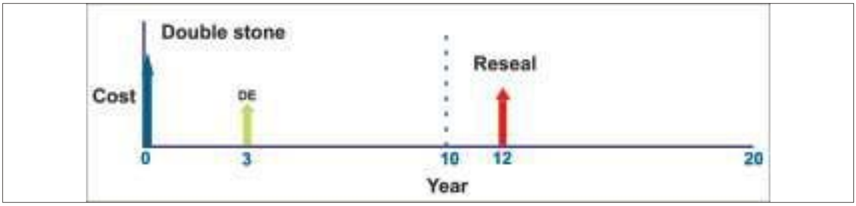


Figure 6 : Typical life-cycle strategy - double seal

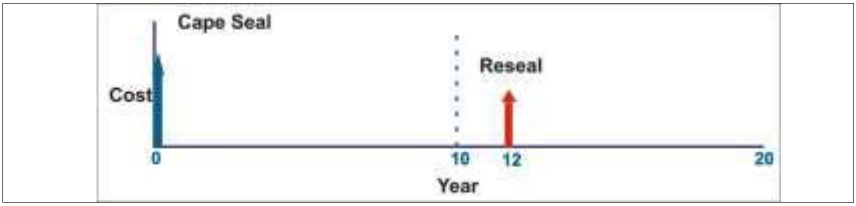


Figure 7 : Typical life-cycle strategy - Cape seal

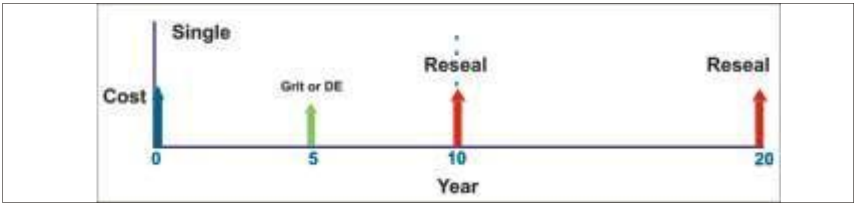


Figure 8 : Typical life-cycle strategy - single seal

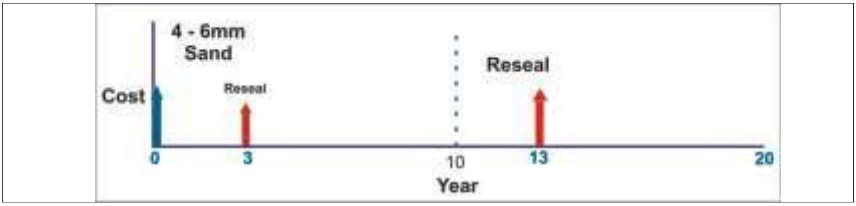


Figure 9 : Typical life-cycle strategy - 4 - 6 mm sand seal

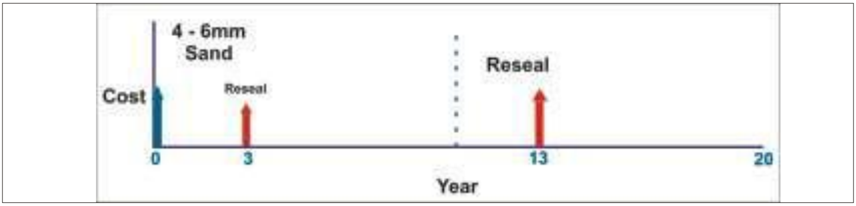


Figure 10 : Typical life-cycle strategy - 8 - 10 mm sand seal

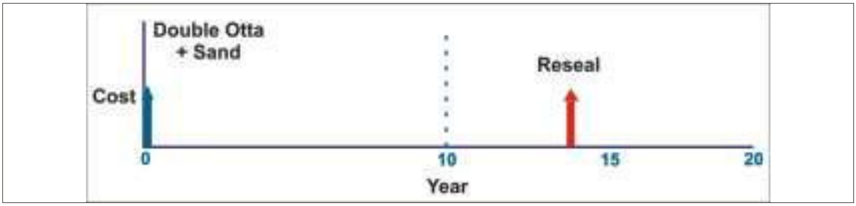


Figure 11 : Typical life-cycle strategy - double Otta seal plus sand

Notes

- DE refers to diluted emulsion rejuvenation spray application;
- Grit refers to minus 4,75 mm coarse sand seal

Should uncertainty exist about the maintenance capability and acceptance of road asset management principles, the selection of short term options is not recommended.

Safety and contractual requirements: Requirements in terms of safety might be the primary reason for surfacing the road (e.g. to ensure skid resistance or to channelise traffic into lanes requiring macro-texture and line marking). In such cases surfacing types with low macro-texture or loose sand should be avoided, namely:

- Continuously graded asphalt;
- Slurry;
- Sand seals; or
- Otta seals.

When line marking is required soon after construction, any surface type with loose sand that must be broomed back onto the surface, should be avoided namely:

- Sand seals;
- Otta seals.

Notes

- Single seals blinded with sand soon lose the excess sand, without compromising the integrity of the seal;
- Coarse sand (grit) has been precoated successfully and does not require any back-brooming.

Management and maintenance strategies of road authorities differ. Several authorities appoint contractors to construct within a limited time period, with no further obligation apart from the correction of defects occurring within the first year. Others have longer term maintenance contracts in place.

The choice of surfacing should take into account the type of contract, and contracts should be adjusted to provide for the required processes and maintenance requirements. As an example, guidelines for construction of a double Otta seal state the following:

- Fifteen passes with heavy pneumatic roller and one pass with 10-12 ton steel roller;
- Fifteen passes with heavy pneumatic roller for two days after construction;
- Maximum traffic speed of 50 km/h for 2 - 6 weeks after construction;
- Min 8 - 12 weeks between first and second layer;
- Back-brooming of sand for four weeks;
- Provision for a sand blinding team for eight weeks during first hot season;
- Permanent road markings delayed for as long as possible.

Urban or rural drainage systems: Whereas water accumulating on a road in the rural environment is shed off the road as soon as possible, urban drainage utilises the road to transport the water to designated outlets, such as stormwater pipe inlets.

Loose sand from sand seals, sand blinding layers and Otta seals could create severe problems when washed into sub-surface drainage systems. These type of surfacings are therefore, not recommended where such drainage systems exist.

Experience from previous studies highlighted the sensitivity of stone seals as first seals in the urban environment, especially in developing areas with loose aggregate, sand or other building materials on the surface resulting in ravelling of the aggregate. Several cases were also recorded of fast-flowing stormwater on the road surface loosening stones from the surface. The use of stone seals as initial construction seals is, therefore, not recommended in the urban environment.

Steep gradients: Steep grades influence both the constructability and the performance of the surfacing.

Spraying of binders on steep grades could become difficult, both from operating the equipment and run-off of low viscosity binders such as emulsions and cut-back binders. Table 2 provides guidelines from practitioners regarding the maximum grades for application of specific binder types.

Table 2: Recommended maximum gradients for application of binder types

Binder type	Maximum gradient
Polymer modified hot binders	+12%
Bitumen grade: 70/100 pen* 150/200 pen	12% 10%
Cutback bitumens: MC 3000 MC 800	8% 6%
Emulsions: 60%, 65%	6% 8%

Notes

- These values are only approximate and highly dependent on road temperatures, texture and the permeability of the existing surface. The operator's own experience should be added to this table to obtain more reliable values;
- The maximum gradient refers to the maximum gradient resulting from the vertical alignment and camber/elevation of the road, and not only to the vertical alignment.

* Formerly 80/100 pen grade.

Due to the traction of specifically heavy vehicle tyres, thin surfacings and single seals seldom perform well on steep grades. Cases have also been observed where thin asphalt and slurry surfacings have "shoved" on slick sub-strata such as stabilised bases. A practical hint on such sub-strata is to either use thick asphalt, or to facilitate more friction by rolling the first seal aggregate layer with a heavy steel wheel roller, forcing some embedment.

Steep gradients in the urban environment also cause storm-water running at higher speeds, resulting in more damage.

Further observations indicate that washing/laundry is often done at communal standpipes using any detergent available. Run-off from these stand-pipe basins erodes the bituminous surfacing, especially if the water is channelised by sand or debris. The rate of erosion (up to 5 mm per annum) highlights the need to avoid thin surfacings.

Steep gradients also require special attention to skid resistance in dry and wet weather (refer section on ***Safety and contractual requirements,*** Section 3.3.1).

Turning actions: Macrotexture refers to the large scale texture represented by the stone particles in a surfacing. These provide hysteretic (deformation) friction and also escape paths for water.

The turning action of vehicles causes horizontal friction perpendicular to the roll direction which results in ravelling of the aggregate. Typically, the greater the macrotexture, the higher the horizontal forces on individual aggregate particles and the higher the risk of ravelling. Stone seals, and in particular single seals, are therefore more sensitive to damage during their early life while the binder is still soft.

Loose material (aggregate and/or sand) often gathers at intersections as a result of ravelling or collection of material from gravel access roads. Such loose material acts as grinding paste, aggravating the situation in terms of aggregate loss. Therefore, thin surfacings such as sand seals are not suitable where sharp turning actions occur.

As discussed above, shoving of the bituminous surfacing could occur on smooth bases as a result of turning or braking actions. Slurry surfacings/microsurfacings and thin asphalt are vulnerable in these situations.

The thicker (and stronger) the surfacing and the smoother the surface, the lower the risk of shoving and/or ravelling.

Notes

- The best performing bituminous surfacings at intersections are thick asphalt (>30 mm), Cape seals (preferably with 19 mm aggregate) and slurry-bound Macadam (30 mm). Should conventional continuous graded asphalt be found not to perform well as a result of high temperatures and high volumes of heavy vehicles, the following alternatives could be considered namely:
  - Polymer modified asphalt;
  - Open graded asphalt with epoxy slurry;
  - Segmented concrete blocks (80 mm);
  - Concrete.
- Where occasional heavy vehicle turning actions occur on a road (e.g. access roads to small settlements or farm accesses) the following treatments to stone seals will improve the performance at the intersections:
  - Spreading a loose layer of sand after construction of the stone seal;
  - Adding a fogspray to the stone seal and spreading a coarse sand on the tacky binder (after breaking of the emulsion);
  - Spreading a fine slurry into the voids of the stone seal.

Institutional capacity and maintenance capability: Where adequate surveillance and intervention programmes fall beyond the capacity of a road authority (numerous regional municipalities could fall within this category), more fail-safe or low risk surfacings should be adopted for any given set of circumstances of the environment and traffic.

Several sites have been inspected as part of this study and the previous study where the conclusion was drawn that if the road was resealed in time or maintenance to the seal was applied, there would be no need for pavement rehabilitation.

Initial surface dressings such as thin slurry, sand seals, singe seals and even double stone seals could be highly sensitive to maintenance in the form of patching of ravelled areas or adding additional binder e.g. diluted emulsion spray. Failure to do timeous maintenance could result in loss of the surfacing and rapid deterioration of the base.

The lowest risk surfacings are asphalt, Cape seals, thick microsurfacings and thick graded aggregate seals e.g. double Otta seals.

Construction risks: General: The performance of bituminous surfacings is highly dependent on the quality of workmanship during construction. In this regard, the performance in terms of long term skid resistance should be separated from the performance in terms of aggregate loss/ravelling or surfacing failures/delamination (refer TMH9).

Should the purpose of surfacing be to provide a dust free surface and to protect the base material, surfacing types such as asphalt, graded aggregate seals, thick slurries/microsurfacings and combination seals pose the lowest risk to construction related problems.

Notes

- Asphalt and microsurfacings are assumed to be well controlled during mixing and placing;
- The structure of combination seals such as Cape seals and slurry-bound Macadam surfacings make them less sensitive to aggregate loss;
- Graded aggregate seals such as Otta seals and thick graded sand seals are typically constructed with soft binders at high application rates, migrating upwards and holding the aggregate particles in place;
- Stone seals are extremely sensitive to excessively low application rates, cold temperatures and rain soon after construction.

Should good skid resistance be required, the lowest risk seal type is considered to be a Cape seal.

Quality:

- **Plant:** Construction plant in poor condition typically results in poor distribution of binder, over-application of aggregate and insufficient rolling. The seal types with the lowest risk of failure are double graded aggregate seals or single graded aggregate seals with a sand seal on top, provided cut-back binders are used;
- **Staff:** Good supervision with experienced staff and quality control during surfacing operations is essential regardless of the surfacing type. Graded aggregate seals typically require the lowest level of quality control;
- **Materials:** Existing specifications for surfacing materials have been developed over time, based on risk and performance. As discussed under Section 4.3.2 several of the existing specifications are considered too conservative and inappropriate for lower volume

roads. Hence, revised guidelines for different traffic and situation categories have been developed and are recommended in this manual.

Method: The method of surfacing (i.e. conventional or labour intensive) determines, to a large extent, which surfacing and binder types should be used. Whereas there are no constraints with conventional methods, labour intensive work requires binders with extended curing times such as cut-back bitumen and stable grade emulsions.

Period of sealing: An embargo period for seal work during winter months (May to September) is maintained by several road authorities in South Africa based on experiences with aggregate loss during cold periods, especially when the minimum night time temperature reduces to below 10°C. Figure 12 and Figure 13 have been prepared to show the average minimum temperatures at different centres in South Africa.

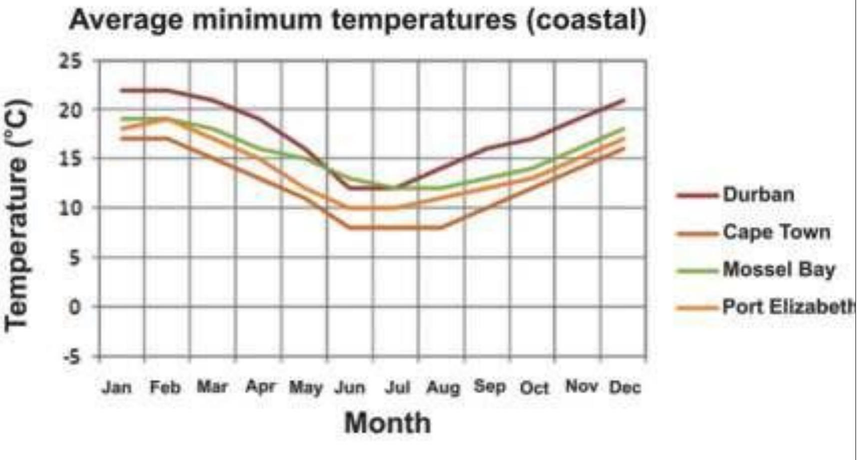


Figure 12 : Average minimum temperatures (coastal)

Figure 13 : Average minimum temperatures (inland)

Although other factors, such as rainfall in combination with temperature also increase the risk of problems during sealing, these figures indicate that the risk of sealing during winter months could be different for different centres.

Notes (based on practitioners' feedback)

- Summer grade polymer modified binders are highly sensitive to night temperatures below 10°C;
- Winter grade polymer modified binders have been used with success, even on highly trafficked roads. It is recommended that these products are only used at the beginning to middle of winter due to the slow evaporation of cutters;
- The minimum road surface temperature requirement for hot binders is 25°C. However, the use of cut-back bitumens and emulsions extend the working time for the contractor;
- Further guidance for cutting back of bitumen is given in TRH3 (Appendix I);
- The temperature of surfacing aggregate is usually not specified. Cold aggregates will increase the risk of aggregate loss;
- When temperatures drop or when rain is expected, the road should be closed (if possible for 48 hours). The road should be opend to traffic only when the surface temperature has increased to above 25°C;
- Graded aggregate seals and sand seals are extremely sensitive to rain prior to the binder migrating to the top of the layer.

Micro climates: Care should be taken when micro-climates occur that are different from the general surfacing project climate. Typical situations are:

- Shady areas (including bridge shadows);
- Road sections at higher altitudes;
- High humidity areas.

A general rule of thumb is to apply 0,2 – 0,4 l/m^2 more net binder to colder micro areas and/or to add an extra fogspray with coarse sand (grit) if possible.

Base type and quality: If a low volume surfaced road is to perform well, it is absolutely critical that the base be properly compacted without any loose material.

Due to the type of base material and the climatic conditions at the time of sealing, it is possible that the embedment potential, based on the ball penetration test[5], could be high. Although provision is made in seal design methods for embedment, the general recommendation is not to seal with stone seals (especially 13,2 mm and 9,5 mm) when the ball penetration values exceed 4 mm [6,7].

Strategies adopted to reduce the risk of embedment are:

- Apply a surfacing type without risk of embedment (e.g. asphalt, graded aggregate seal or sand seal; or
- Use an inverted double seal, where the small aggregate acts as an armouring layer; or
- Increase the spread rate of the larger aggregate to provide more friction between the aggregate particles.

The surface deflection on light pavement structures could be high. This would require, ideally, a highly flexible surfacing type (in all climatic conditions) with slow ageing characteristics. Although this statement has been made in the literature[8], it is important to understand where the deflection originates in the pavement structure. Unless a soft layer is present directly under the bituminous surfacing, the majority of all surfacings should perform well on a properly compacted base provided the seal is not allowed to become excessively dry and subject to fatigue cracking.

Note

The appropriate seal type for reseal should take into consideration defects such as cracking, texture and aggregate loss, which should not be present on a newly constructed base.

Traffic volume: The typical distribution of vehicle types on a road includes 5 - 20% heavy vehicles (i.e. trucks and buses). The balance consists of cars, light delivery vehicles and combi-taxis.

Although all vehicles contribute to polishing of the aggregate and scuffing at corners/sharp curves, the main damage to bituminous surfacings is caused by heavy vehicles.

TRH3 indicates that all surfacing types, except for thin sand seals, are appropriate up to 2 000 Equivalent Light Vehicles (ELVs) per lane per day. This equates to an average daily traffic in both directions (ADT) of approximately 800 vehicles.

Note

For narrow roads without centre line marking 2 000 ELVs equates to approximately 400 ELVs.

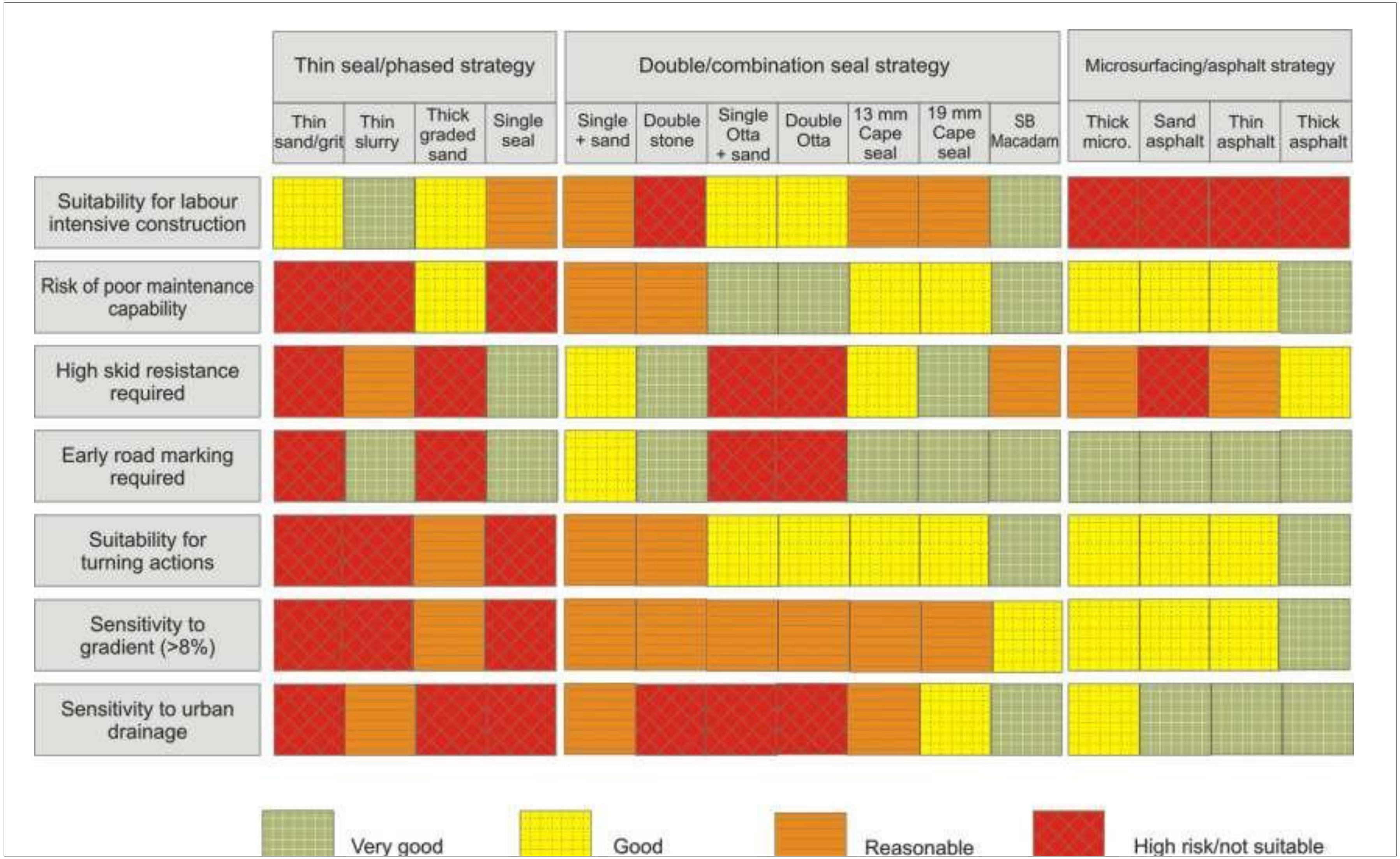
Unless the base is very soft and/or heavy vehicles are overloaded, embedment of seal aggregate has hardly ever been recorded as the cause of seal failure on low volume roads.

Cost: The cost of a bituminous surfacing is highly dependent on the construction costs, the binder and aggregate costs and the haul distance costs of the binder and the aggregate. Cost variations, cost ratios and trends of cost increases are discussed in more detail in Section 5.

3.3.2 Selection summary

Table 3 provides a quick guideline of bituminous surfacing types and the appropriateness in specific situations.

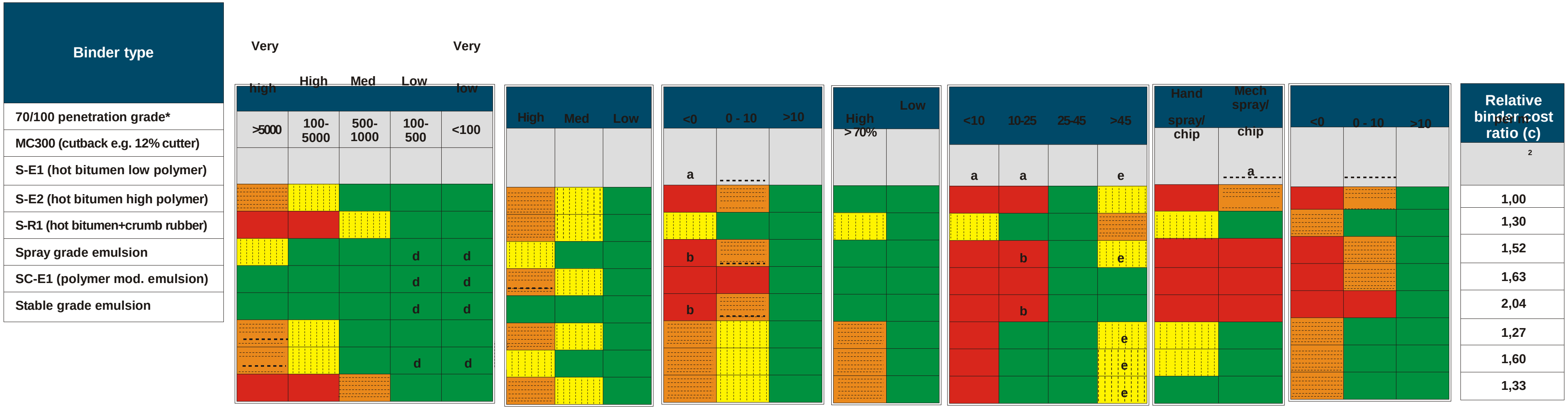
Table 3 : Selection guideline (initial surfacings)



	Thin seal/phased strategy				Double/combination seal strategy							Microsurfacing/asphalt strategy			
	Thin sand/grit	Thin slurry	Thick graded sand	Single seal	Single + sand	Double stone	Single Otta + sand	Double Otta	13 mm Cape seal	19 mm Cape seal	SB Macadam	Thick micro.	Sand asphalt	Thin asphalt	Thick asphalt
Suitability for labour intensive construction	🟨	🟩	🟨	🟧	🟧	🟥	🟨	🟨	🟧	🟧	🟩	🟥	🟥	🟥	🟥
Risk of poor maintenance capability	🟥	🟥	🟨	🟥	🟧	🟧	🟩	🟩	🟨	🟨	🟩	🟨	🟨	🟨	🟩
High skid resistance required	🟥	🟧	🟥	🟩	🟨	🟩	🟥	🟥	🟨	🟩	🟧	🟧	🟥	🟧	🟨
Early road marking required	🟥	🟩	🟥	🟩	🟨	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Suitability for turning actions	🟥	🟥	🟧	🟥	🟧	🟧	🟨	🟨	🟨	🟨	🟩	🟨	🟨	🟨	🟩
Sensitivity to gradient (>8%)	🟥	🟥	🟧	🟥	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟩
Sensitivity to urban drainage	🟥	🟧	🟥	🟥	🟧	🟥	🟥	🟥	🟧	🟨	🟩	🟨	🟩	🟩	🟩

🟩 Very good 🟨 Good 🟧 Reasonable 🟥 High risk/not suitable

Table 4. Guide for binder selection



Binder type	Very high	High	Med	Low	Very low																		Relative binder cost per m² ratio (c)
	>5000	100-5000	500-1000	100-500	<100	High	Med	Low	<0	0 - 10	>10	High > 70%	Low	<10	10-25	25-45	>45	Hand spray/ chip	Mech spray/ chip	<0	0 - 10	>10	
									a					a	a		e		a				
70/100 penetration grade*	🟧	🟨	🟩	🟩	🟩	🟧	🟨	🟩	🟥	🟧	🟩	🟩	🟩	🟥	🟥	🟩	🟨	🟥	🟧	🟥	🟧	🟩	1,00
MC300 (cutback e.g. 12% cutter)	🟥	🟥	🟨	🟩	🟩	🟧	🟨	🟩	🟨	🟩	🟩	🟨	🟩	🟨	🟩	🟩	🟧	🟨	🟩	🟧	🟩	🟩	1,30
S-E1 (hot bitumen low polymer)	🟨	🟩	🟩	🟩 d	🟩 d	🟨	🟩	🟩	🟥 b	🟧	🟩	🟩	🟩	🟥	🟥 b	🟩	🟨 e	🟥	🟥	🟥	🟧	🟩	1,52
S-E2 (hot bitumen high polymer)	🟩	🟩	🟩	🟩 d	🟩 d	🟧	🟨	🟩	🟥	🟥	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟧	🟩	1,63
S-R1 (hot bitumen+crumb rubber)	🟩	🟩	🟩	🟩 d	🟩 d	🟩	🟩	🟩	🟥 b	🟧	🟩	🟩	🟩	🟥	🟥 b	🟩	🟩	🟥	🟥	🟥	🟥	🟩	2,04
Spray grade emulsion	🟧	🟨	🟩	🟩	🟩	🟧	🟨	🟩	🟧	🟨	🟩	🟧	🟩	🟥	🟩	🟩	🟨 e	🟨	🟩	🟧	🟩	🟩	1,27
SC-E1 (polymer mod. emulsion)	🟧	🟨	🟩	🟩 d	🟩 d	🟨	🟩	🟩	🟧	🟨	🟩	🟧	🟩	🟥	🟩	🟩	🟨 e	🟨	🟩	🟧	🟩	🟩	1,60
Stable grade emulsion	🟥	🟥	🟧	🟩	🟩	🟧	🟨	🟩	🟧	🟨	🟩	🟧	🟩	🟥	🟩	🟩	🟨 e	🟩	🟩	🟧	🟩	🟩	1,33

*** Formerly 80/100 pen grade**

🟥 High risk

🟧 Generally not recommended

🟨 Medium risk but good experience recorded

🟩 Low risk

a Cutting back (2 - 12%) could reduce risk - refer TRH3
b Cutting back up to 4% on single seals has been done with success to reduce risks
c Based on typical application rates and bulk cost per litre
d Modified binders not often used for initial seals on low volume roads due to costs
e Keep road closed for first two days

Additional notes:

1. Not all binders are suitable for all seal types
2. Soft binders, e.g. MC3000 preferred on very low volume roads
3. Keeping the road closed during first cold nights will reduce the risk of stripping
4. Single or double seals with emulsions normally require a cover spray

Binder description

70/100* - 70/100 penetration grade bitumen
MC3000 - Medium cut-back bitumen (typically 70/100 penetration grade bitumen with 12% cutter)
S-E1 - Hot polymer modified bitumen (typically less than 3% polymer)
S-E2 - Hot polymer modified bitumen (typically more than 3% polymer)
S-R1 - Rubber crumb hot modified bitumen (29% rubber crumbs used in South Africa)
Spray grade emulsion - Typically 65% cationic spray grade bitumen emulsion
SC-E1 - Polymer modified emulsion (typically 5% SBR polymer)
Stable grade emulsion - Cationic or anionic stable grade emulsion

* Formerly 80/100 penetration grade bitumen

3.4 Selection of temporary surfacings

3.4.1 Use of temporary surfacings

Temporary surfacings are mostly used in South Africa to safely accommodate traffic on temporary deviations or to protect the base during half-width construction until the final surfacing can be applied over the full width. The latter situation often occurs as a result of seal embargos during the cold winter period.

3.4.2 Considerations

Traffic and safety issues: Temporary deviations normally carry dual direction traffic managed through stop-go control. These deviations are often constructed without a high level of quality control, using local or marginal materials and are normally narrow, not allowing traffic wander. Hence, the damage, especially that caused by heavy vehicles, could be much more than on a properly designed and constructed road.

Although the benefits in terms of savings in vehicle operating costs might not warrant the costs of surfacing, the negative effect of dust on road user safety and on the main construction activities (e.g. sealing) could dictate a decision to surface the deviation. It should further be noted that speeds are kept low and that skid resistance is, therefore, not normally a concern.

Duration and traffic volume

Table 5 shows the recommended surfacing types based on practitioners' feedback.

Table 5. Recommended surfacing types based on practitioners feedback.

Duration of temporary deviation (months)	Traffic volume		
	500 vpd	2 500 vpd	10 000 vpd
1	Gravel (DP)	DP	DP
2	Gravel (DP)	S1	S1
3	DP	S1	S1
4 to 5	S1	S1	S2
6	S1	S1	S2
7	S1	S2	Asphalt
8 to 9	S1	S2	Asphalt
10 to 12	S1	Asphalt	Asphalt
13 to 24	S2	Asphalt	Asphalt

Notes

- Gravel - properly compacted wearing course (refer TRH20);
- DP - Dust palliative (both bituminous with sand or chemical products could work);
- S1 - Single seal with cover spray and preferably with sand blinding or thick graded sand seals;
- S2 - Multiple or combination seal type e.g.:
  - Double seals (13,2 plus 6,7 mm);
  - Stone and grit seals (9,5 or 13,2 mm plus grit);
  - Stone and slurry combination (9,5 mm plus slurry used with success);
  - Otta seals (preferably dense graded with soft binder).

Winter sealing

As a result of the winter seal embargo, temporary surfacings are often constructed during this time. The most successful temporary surfacing types on which a stone seal could be constructed after winter are:

- Single seals (6,7 mm and 9,5 mm) using an emulsion tack coat and cover spray;
- Cape seals (9,5 mm and 13,2 mm) with closely packed aggregate;
- Microsurfacings (8 mm).

Sand seals and graded aggregate seals are often still too soft (high ball penetration) to accommodate the subsequent construction of a stone seal. If the seal is only required for a temporary deviation which will be removed after opening of the road, then sand seals and graded aggregate seals constructed with soft binders (e.g. MC3000) are appropriate.

Pavement and base quality

Previous recommendations suggested the use of modified binders in cases where the quality of the base and pavement layers is suspect. However, experience over the past decade indicates that this recommendation is not valid for all modified binders.

High stress wheel actions

Traffic actions such as turning, braking and acceleration occur on temporary deviations at stop-go controls, intersections and accesses. It is recommended that these areas be treated differently if a thin temporary seal (S1 in Table 5) is selected for the project.

Cost

Cost plays a major role in the selection of a temporary seal. In this regard it should be noted that the surfacing life is relatively short and that several specifications for the aggregate could be relaxed to facilitate significant savings (refer Section 4.3.2).

Notes

- Waste fractions from crushing and screening processes could be evaluated for use;
- Local material could be screened for use in an Otta seal.

3.4.3 Selection: Practical considerations and examples

Poor performance of temporary surfacings (Photograph 1) is often observed and has led to recommendations that single seals are not appropriate for this purpose.

However, some experiments on national routes in South Africa carrying up to 60% heavy vehicles have shown that even 9,5 mm single seals can perform without any defects for more than a year.

Photograph 1: Single 13,2 mm seal without cover spray

Photograph 2: Temporary 9,5 mm single seal without emulsion cover spray

Photograph 2 shows a temporary 9,5 mm single seal on a widening contract, constructed with an emulsion tack coat but without an emulsion cover spray. Even with an increased binder in the tack coat the seal is still sensitive to traffic abrasion and ravelling.

Applying the same quantity of net cold binder, but using emulsion in the tack coat, and undiluted emulsion of up to 60/40 (emulsion/water) dilution as a cover spray, eliminated the sensitivity to ravelling.

Note

Severasl examples exist where a 6,7 mm single seal was successfully used as a temporary seal to accommodate traffic for more than three months. The typcal net cold binder application rate for this type of temporary seal is 0,8 l/m^2

Experience indicates that for a single seal as a temporary seal, the quantity of binder, as determined through the TRH3 simplified design method, should be at least 20% more than the minimum suggested and up to 50% more in the case of winter sealing, and constructed with a cover spray of emulsion/diluted emulsion.

Photograph 3 shows a 9,5 mm temporary single seal on the N1/14, carrying extremely high heavy vehicle traffic for a year. The seal was placed directly on the primed crushed stone base in winter with the following application rates:

- Tack coat - 1,1 l/m^2 SC-E1 (65% cationic polymer modified emulsion);
- Cover spray - 0,8 l/m^2 65% cationic spray grade emulsion (diluted 70/30 water/emulsion).

Photograph 3: Single 9,5 mm seal with emulsion cover spray (N1/14 after 1 year)

Photograph 4 shows a microsurfacing placed on a foam-treated base (road widening), as a temporary seal. The design bitumen quantity was 6,5%. Apart from eliminating irregularities on the foamed base that was damaged by traffic, the microsurfacing assisted in obtaining a surface level with the existing road and provided a smooth-textured surface similar to the existing road after texture treatment.

Photograph 4: Microsurfacing (8 mm)

One of the lowest risk temporary surfacings for temporary winter seals is a 9,5 mm Cape seal as shown in Photograph 5. This seal type is also quite effective in handling heavy vehicle turning actions as shown in Photograph 6. The seal was constructed using precoated stone with 1,0 l/m^2 SC-E1 65% emulsion as tack coat, no cover spray and one layer of medium-fine slurry with 8% bitumen content.

Photograph 5: Temporary 9,5 mm Cape seal after one year

Photograph 6: Temporary 9,5 mm Cape seal on an intersection

Photograph 7: 9,5 mm single seal with natural fine sand blinding

Photograph 7 shows the surface of a 9,5 mm single seal with a sand blinding layer applied after the emulsion cover spray has cured. Initial rolling (2 passes) with a light steel wheel roller orientates the aggregate and increases the surface area in contact with the binder.

Several cases have been mentioned by practitioners in which graded aggregate seals such as Otta seals and coarse sand seals provide excellent service on temporary deviations.

The key to good performance with these types of seals on deviations lies in the use of a high application of a soft binder such as MC3000 and, preferably, a high percentage of fines and dust (e.g. 7 - 25% minus 0,425 mm and 3 - 10% minus 0,075 mm) as recommended for dense graded Otta seals[9].

3.5 Forestry roads

3.5.1 Considerations

Forestry roads are generally located in wet and hilly areas (steep gradients and short radius curves), with rural drainage (no kerbs), carrying heavily loaded trucks with tandem or tridem axle configurations (often overloaded). The decision to surface is dependent on the purpose of the specific road section and is normally based on economic principles. Management of the forestry area and frequency of harvesting specific species dictate the required level of service and the need for temporary or permanent upgrading.

Although these roads are privately owned, the maintenance levels tend to be low resulting in a preference towards stronger surfacing types such as asphalt, thick Otta seals and Cape seals.

Note

- Smooth base surfaces could result in shoving of the surfacing;
- Due to generally low speeds, a layer of sand on the bituminous surface would reduce the risk of shoving or ravelling.

3.5.2 Innovative solutions

Due to the remoteness of small projects in forestry areas, the surfacing or resurfacing of roads could be expensive. However, as shown in photograph 8 and 9, De Wet[10] proved that slurry surfacings could be constructed using a simple adjustable spreader box, available equipment and inexperienced staff.

Photograph 8: Small scale slurry operation

Photograph 9: Slurry surfacing on forestry road

3.6 Game parks and nature reserves

3.6.1 Considerations

When considering roads in game parks and nature reserves, the need for upgrading, the required level of upgrading and the appropriate surfacing type to use depend largely on:

- Volume of traffic;
- Turning and braking actions of buses and other heavy vehicles;
- Environmental sensitivities;
- Gravel wearing course properties and climate during peak seasons;
- Availability of suitable surfacing aggregate;
- Maintenance capability and strategy;
- Preferences of the organisation and involved environmentalists;
- Costs.

Apart from the successes with double sand seals in the Kruger National Park[10] and other surfacing types elsewhere (e.g. Otta seals, combination seals and asphalt) several experimental sections have been constructed and are being monitored to evaluate the structural performance and environmental impact of chemical and bituminous additives to the gravel wearing course.

Providing it is visually acceptable to the organisation to use a bituminous surfacing, the main consideration for selection lies in the potential actions of heavy vehicles (buses) and the maintenance capability of the organisation. Whereas double sand seals and Otta seals generally perform well on lightly trafficked road sections, they are not suitable at intersections, parking areas and look-out points unless a layer of loose fine sand on the surface is maintained.

3.7 Footways, cycle lanes and non-motorised traffic

Any surface used by pedestrians or bicycles should ideally be smooth textured. Heavy vehicles are either excluded or limited. Therefore slurry seals (6 mm, see Photograph 10), slurry-bound Macadam seals, microsurfacing and thin asphalt are considered the most appropriate. Sand seals and graded aggregate seals require vehicle tyre action to create a proper surfacing and are, therefore, not ideal for footways and cycle lanes.

Coloured surfacings could be used to demarcate footways and cycle lanes as shown in Photograph 11 and Photograph 12.

Several options for colouring and friction requirements could be evaluated[11].

Photograph 10: Slurry applied on footway (side walk)

Photograph 11: Coloured slurry on cycle lane

Photograph 12: Cycle lane and footway coloured surfaces

4 Appropriate standards

4.1 General principles

The term "appropriate standards" does not mean lower standards - depending on what is being considered, the term could even mean that the appropriate standard should be higher than normal.

This section provides references to relevant design documentation and discusses recommended adjustments to existing South African standard specifications for low volume surfaced roads.

4.2 Design

4.2.1 Reference documentation

The design of bitumen surfacings is well described in published documentation as referred to in Table 6, and is therefore, not covered in this manual.

Table 6 : Reference to design documentation

Surfacing type	Relevant documentation
Single and double stone seals	TRH3[7]
Cape seals	TRH3, WCPA (12), Manual 28, van Zyl *et al*[13]
Slurry and microsurfacing	Sabita Manual 28[14], TRH3
Otta seals	Botswana DOT[9], TRH3
Sand seals	TRH3
Sand asphalt	Sabita Manual 18[1]
Asphalt	Sabita Manual 24[15]
Thin asphalt	Sabita Manual 27[16]
Slurry-bound Macadam	Sabita Manuals 11[17] and 12[18]

4.3 Materials

4.3.1 Bitumen specifications

No adjustments to existing bitumen specifications are recommended. The relevant specification numbers for conventional binders are shown in Table 7.

Table 7 : Reference to bitumen specifications

Specification Number	Title	Grade Designations
Bitumen		
SANS 4001-BT1[1]	Penetration grade bitumen	35/50 * 50/70** 70/100*** 150/200
SANS 4001-BT2[2]	Cutback bitumen	MC10 MC30 MC3000
Bitumen emulsions		
SANS 4001-BT3[3]	Anionic bitumen road emulsions	Spray type Stable mix type
SANS 4001-BT4[4]	Cationic bitumen road emulsions	Spray type Premix type Stable mix type
SANS 4001-BT5[5]	Invert bitumen emulsion Spray type	Prime
Modified binders (guideline limits only)		
TG 1	*The use of modified binders in road construction,* 2nd edition, 2007	All modified hot binders and emulsions

Notes

1	Formerly SANS 307	*	Formerly 40/50
2	Formerly SANS 308	**	Formerly 60/70
3	Formerly SANS 309	***	Formerly 80/100
4	Formerly SANS 548		
5	Formerly SANS 1260		

4.3.2 Appropriate aggregate specifications

Background: An important cost component in the provision of bituminous surfacings is the location, processing and haulage of a suitable aggregate for use in the bituminous surfacing. In many rural areas (where the provision of this type of road is currently greatest), there are very few commercial sources of suitable surfacing stone within economic haulage distance.

Although the aggregate cost generally makes up only about 17% of the total seal cost for an average seal, this can increase significantly in remote areas, particularly as haulage costs increase rapidly with rising fuel prices (as do bitumen prices). Wright *et al*[19] showed that savings of up to 30% of the surfacing stone cost and as much as 7% of the total cost of the seal can be achieved by using aggregate outside the conventional specifications.
The use of appropriate surfacing stone can therefore significantly affect the cost (and the type) of the seal. It has been shown by a number of studies (Woodbridge *et al*[20], Woodbridge and Slater[21], and Paige-Green [22,23,24,25] that the current specifications (COLTO[26]) are too strict for applicability to most appropriate seals on lightly trafficked roads. If local materials derived by ripping and screening can be used instead of aggregate produced by blasting and crushing, significant savings can accrue. This would entail a reduction in the minimum aggregate strength as described by Woodbridge and Paige-Green.

A reduction in aggregate strength may entail a change in some of the design criteria, and it is likely that natural materials would be more porous than conventional aggregates necessitating pre-coating. It is also likely that the aggregate shape would be more variable and properties such as the Average Least Dimension (ALD) would be erratic. This would certainly affect such issues as the binder application rate, but it would be better to err on the conservative side and provide an excess of binder.

Observation of numerous low volume roads indicate that those with slightly excess binder perform considerably better and last much longer, despite often showing significant flushing. This is, however, considered to be a tolerable problem on lightly trafficked roads, and even though the skid-resistance may be slightly compromised, it will always remain better than on an equivalent unsealed road in wet conditions.

Where the material is such that it is not suitable for a conventional chip seal, the use of non-traditional seals should be considered. Otta seals, for instance, can tolerate a much weaker aggregate (min 10% FACT of 90 kN) than a conventional chip seal (210 kN) or even one with a relaxed specification (150 kN).

Sand seals should also be considered as suitable low cost surfacings for light pavement structures. These can be constructed using sands from relatively mature or old river systems, usually directly from source but occasionally requiring some screening to remove small amounts of oversized and organic materials (roots and wood). The advantage of this material source is that it is usually considered a renewable resource as it is replenished each time the river floods and has no lasting environmental problems.

It is essential that the initial application of sand or Otta seals be followed within three to five months with a second application. Experience has shown that the thin nature of these seals makes them prone to localised punching and ravelling. However, the application of the second seal reduces this potential significantly.

Aggregate properties could be divided into the basic (intrinsic) properties and processed properties. Appropriate standards for roads carrying less than 500 vpd are provided where relevant.

Basic properties:

Hardness (crushing strength): Standards for surfacing aggregate for light pavement structures in various southern hemisphere and African countries are lower than those in South Africa, with 10% FACT values of 120 and 140 kN specified in Zimbabwe and Kenya respectively, and 150 kN in Australia. It should be noted that all three of these countries also specify a soundness test with a maximum of between 12 and 20% loss from the sodium/magnesium sulphate soundness test. A maximum ACV of 30 (equivalent 10% FACT of 120 kN) has been specified for lightly trafficked roads in the United States (M283-83 in AASHTO, 1986).

The use of aggregate with an ACV of greater than 50% in Kenya resulted in significantly more potholing than more conventional stone (Woodbridge *et al*, 1991) and it has been suggested that a maximum ACV of 30% should be allowed for low volume roads (Netterberg and Paige-Green[27]). A maximum ACV of 30 or 35% is recommended in Nigeria[28] (no details are given about when the specific limits should be used). A study of seven screened laterite gravels indicated that only one material passed the ACV of 30% specification, two materials complied with the 35% limit and the rest were considered border line. The weakest material had an ACV of 42%. The control material used in the testing was a dolerite, which had an ACV of 24%, lower than the standard requirement of 21% used in South Africa.

A wider review of the literature showed that very little research into the relaxation of specifications for surfacing aggregate has been carried out.

TRL (UK) carried out a project to investigate the use of marginal duricrusts in Botswana (Woodbridge *et al*, 1991; Woodbridge and Slater, 1995). Accelerated testing was also carried out in the United Kingdom using Botswana and British aggregates. The materials tested varied in hardness between 160 and 240 kN 10% FACT (one UK limestone had a 10% FACT of 140 kN), which would hardly be considered marginal surfacing aggregate in many cases. It was concluded from this study that minimum dry 10% FACT values of 180, 150 and 130 kN (at least 75% of this value when soaked) can be used for traffic of 3 million, 0,8 - 3 million and 0,8 million equivalent standard axles respectively (Woodbridge *et al*, 1991). For Botswana specifically, the later report (Woodbridge and Slater, 1995) recommended minimum 10% FACT values of 150 kN for roads with less than 200 ADT and 180 kN for roads with more than 200 ADT.

Durability/soundness: The durability of certain surfacing stones can be a potential problem, although this has seldom been encountered in practice since conventional testing, such as the wet and dry 10% FACT (although not normally considered a direct durability test) eliminates most problem materials as shown in Table 7 below. However, the use of lower limits for this test could result in non-durable materials possibly being considered for use.

There is little experience of aggregate actually decomposing in roads. Many examples of materials considered to be non-durable have proved to be adequate in service where the seal is exposed for less than about 10 years before being resealed. Durability in the context being considered is related to the decomposition of selected minerals in the aggregate due to the type of mineral (olivine, pyroxene, or calcic plagioclase) or as a result of disintegration of the aggregate resulting from expansion of unstable clays (normally smectite) within the aggregate matrix.

Partly weathered (and some unweathered) basic crystalline rocks (dolerite, basalt and gabbro/norite), some tillites and many non-indurated mudstones naturally contain smectite clays. If occurring in sufficient quantities, these will absorb water, swell and disintegrate. No specification is currently available for the quantification of this problem but it is suggested that if more than 2 to 4% (Table 8) of a random sample of at least 40 pieces of the proposed surfacing aggregate show any deterioration after being soaked in ethylene glycol for five days, its durability should be regarded as suspect.

Usually, in these cases, past experience with the material as a surfacing aggregate should be assessed, or specialist advice should be sought. Another potential durability problem can occur when unoxidised sulphide minerals (e.g. pyrites or marcasite) occur in aggregates, usually granites or quartzitic mine wastes. These often oxidise and hydrate rapidly in the seal forming sulphuric acid, which leaves a void in the place of the sulphide and causes significant staining of the road surface. Care should thus be taken when rocks with visible sulphide mineralisation are used for the aggregate.

Table 8 : Permitted percentage disintegration of aggregate for different seals

Seal type	Percentage sample affected by ethylene glycol
Sand, Otta	Not applicable
Single	2
Double	3
Slurry	4

Polished stone value: Polishing of stone by traffic lowers the skid resistance of the surfacing, especially under wet conditions. However, for low volume roads, this is rarely a problem.

Recommended basic aggregate properties for low volume roads: Based on available information, feedback on performance of seals with marginal aggregates in South Africa and applied specifications elsewhere, guideline specifications are provided in Table 9.

Table 9 : Guidelines for basic stone seal aggregate properties

Property	Traffic (AADT)	
	< 200 vpd	200 - 500 vpd
Dry 10% FACT [kN] (min)	150	180
Wet 10% FACT [kN] (min)	75	90
Aggregate Crushing Value (ACV) [%] (max)*	30	25
Polished Stone Value (PSV) (min)	N/A**	45

Note

* ACV not allowed as alternative to 10% FACT on pedogenic materials;
** A value of 45 min is recommended in high risk situations.

Requirements for natural graded aggregate seals (Otta seals) are based on experience provided in the Botswana guideline documents[9].

Processed properties

Grading requirements: Current sprayed seal design methods are based on aggregate conforming to specific particle size distribution, packed shoulder-to-shoulder after rolling. Changing the grading requirements would result in less confidence about the appropriate binder application to prevent both whip-off and bleeding. However, considering the performance of high binder sprayed seals on low volume roads, of which the grading fell within the current COLTO Grade 3 specification (highlighted in Table 9), it is recommended that this set of gradings be accepted for roads carrying less than 500 vpd.

Dust content: Dust (percentage passing 0,075 mm) has a negative effect on the binder-stone adhesion and is normally controlled to a minimum in the case of stone seals and coarse sand seals as shown in Table 10.

Graded aggregate seals on the other hand, ideally require a continuously graded material. A limited amount of dust is acceptable.

Aggregate shape: The shape of aggregate particles is highly dependent on:

- Type of crusher (jaw crushers tend to produce more flaky aggregate);
- Rate of feed;
- Mineralogy (e.g. very hard metamorphic rocks such as quartzite and hornfels (also those with natural cleavage) have a tendency towards flakiness.

Table 10 : Single-sized crushed aggregate specification

Sieve size (mm)	Grade	Percentage passing by mass (nominal size)						
		26,5 mm	19,0 mm	13,2 mm	9,5 mm	6,7 mm	4,75 mm	2,36 mm
37,50	Grades 1&2	100	-	-	-	-	-	-
26,50		85 - 100	100	-	-	-	-	-
19,00		0 - 30	85 - 100	100	-	-	-	-
13,20		0 - 5	0 - 30	85 - 100	100	-	-	-
9,50		-	0 - 5	0 - 30*	85 - 100	100	-	-
6,70		-	-	0 - 5**	0 - 30*	85 - 100	100	-
4,75		-	-	-	0 - 5**	0 - 30*	85 - 100	100
3,35		-	-	-	-	-	0 - 30	-
2,36		-	-	-	-	0 - 5**	0 - 5	0 - 100
	Grade 3	Grading shall comply with the requirements for Grades 1 & 2 with the following exceptions: * 0 - 50 ** 0 - 10						
Fines content: Material passing a 0,425 mm sieve (max)	Grade 1	0,5	0,5	0,5	0,5	0,5	1,0	15,0
	Grade 2	1,5	1,5	1,5	1,5	2,0	2,5	15,0
	Grade 3	N/A	N/A	2,0	2,0	3,0	3,5	15,0
Dust content: Material passing a 0,075 mm sieve (max)	Grade 1	N/A	N/A	N/A	N/A	N/A	N/A	2,0
	Grade 2	0,5	0,5	0,5	0,5	1,0	1,0	2,0
	Grade 3	N/A	N/A	1,5	1,5	1,5	1,5	2,0

Note

* Precoating of the aggregate and/or use of cut-back bitumen or emulsion will reduce the risk of poor adhesion due to high dust contents;

** The standard sieve sizes are likely to change in the near future. However, these have not been finalised at time of this publication.

Particle shape - Average Least Dimension (ALD): The ALD essentially determines the binder application rate to hold the stone while providing a target texture depth.

Several aggregate sources not conforming to the existing COLTO specifications have been used successfully for seal aggregates. Based on the performance of such seals, designs being based on ALD of the available stone and the impact of longer hauling distances, target minimum ALDs for roads carrying less than 500 vpd are provided in Table 11.

Table 11 : Target minimum ALD for low volume roads

Nominal size (mm)	Target Minimum ALD
19,0	10,8
13,2	7,4
9,5	5,0

Note

The ALD targets are not considered critical for good performance on low volume roads and are merely provided to reflect the recommendations of current practitioners to ensure applicability of current design methodologies.

Particle shape - flakiness: The flakiness index determined using TMH1, test method B3, quantifies the degree of flakiness of the aggregate. The more flaky the material, the less uniform will be the thickness of the seal layer and the lower the void content. Specifications provided for Grade 3 aggregate (COLTO) are considered appropriate flakiness limits for low volume roads (see Table 12).

Table 12 : Flakiness Index

Aggregate size (nominal) (mm)	Grade of Aggregate	
	Grade 1	Grade 2 & 3
19,0	25	30
13,2	25	30
9,5	30	35
6,7	30	35

Fines and sand equivalent: The sand equivalent is determined in accordance with SABS 838 or TMH1, Method B19[29]. The purpose of this test is to identify aggregate sources containing detrimental fines or high clay content. The test is carried out by mixing the minus 4,75 mm aggregate component with water and a flocculent, allowing the aggregate component to gravitate and measuring the depth of easily displaceable fines. Low sand equivalent slurry mixes will be sensitive to balling when temperatures increase, and also have excessively high water demand.

Table 13 : Recommended minimum sand equivalent for different seal types.

Surfacing Type	Recommended minimum sand equivalent
Sand seal	30
Otta seal	25
Slurry seal	30
Dust palliative	30

Note

Although the ideal dust content range for slurry seals is considered to be between 5 and 12%, successes have been achieved with dust contents of up to 20% (refer Sabita Manual 28).

4.4 Construction

4.4.1 Principles of relaxation

The performance of a bituminous surfacing is highly dependent on the quality of construction. Feedback and observations during the course of updating this manual indicate that the main reasons for premature failure are related to the construction process and not to design or climatic influences. It is for this reason that strict specifications for equipment, processes and material conformance (COLTO,1998[30]) were developed. The risk of failure as a result of construction equipment and processes is however, different for different surfacing and binder types, resulting in the possibility in certain situations of deviating slightly from COLTO specifications.

Note

Relaxing specifications normally require a higher level of quality control.

4.4.2 Equipment

The basic requirements as specified for any surfacing type in COLTO and other documentation are valid and important. For purposes of applying specific binder and surfacing types on low volume roads, some specifications might be reconsidered (e.g. specifying self-propelled chip spreaders with graded aggregate seals or sand seals).

4.4.3 Processes

The majority of failures on sprayed seals are related to:

- Poor joint construction;
- Transverse distribution of the binder;
- Over or under spray.

In the case of slurry seals, the main reasons for poor performance recorded are:

- Ravelling due to incorrect (usually too low) binder content;
- Bleeding as a result of not taking into account moisture expansion of sand.

Note

Refer to Chapter 13 of the SANRAL Materials Manual for further guidance.

Poor joint construction

Longitudinal joints: Joint failures result from insufficient binder overlap, either as a result of a poor line of spray, insufficient overlap between adjacent sprays or damage caused by the chip spreader running on the newly applied bitumen. Typical examples are shown in photographs 13 and 14.

Proper joint construction can be obtained by:

- Using string lines to guide the distributor;
- Specifying proper binder overlap as shown in Figure 14.

Note

Other configurations could also be used.

Photograph 13: Poor longitudinal joint construction

Photograph 14: Damage by chip spreader

Due to traffic not driving on the centre line, more overlap on the centre line is often recommended. The principle is shown in Figure 15.

Transverse joints: Poor attention to transverse joints typically results in bleeding and pick-up at these positions (Photograph 15). The use of joint paper is illustrated in Photograph 16.

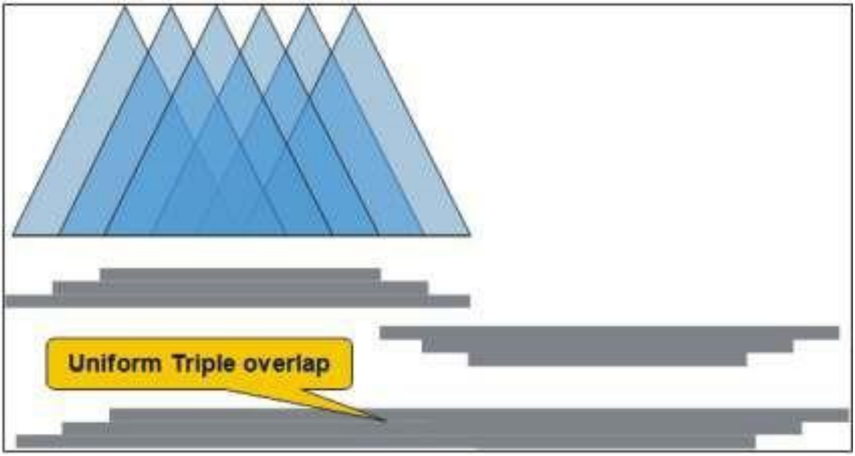


Figure 14: Example of proper binder overlap

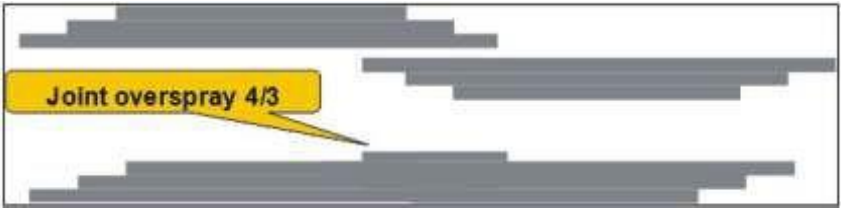


Figure 15: Centre line joint overspray

Transverse distribution: Poor transverse distribution results from either the equipment itself (incorrect alignment of spray nozzles or pressure too low in the spray bar) or incorrect setting of the spray bar height (see Photograph 17).

Photograph 15: Transverse joint problems

Photograph 16: Use of joint paper at transverse joint

Figure 16 illustrates the impact of incorrect spray-bar height.

Photograph 17: Poor spray-bar distribution

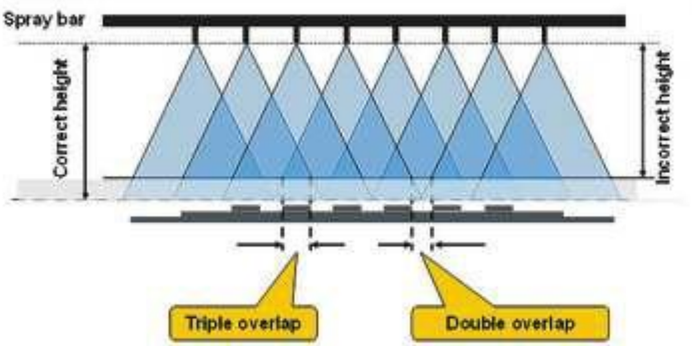


Figure 16: Impact of incorrect spray-bar height

The impact on initial construction seals is significant as shown in Photograph 18.

Photograph 18: Impact of poor transverse distribution

Note

The risk of pavement damage due to poor transverse distribution increases dramatically with:

- Granular bases;
- Single binder application surfacings; and
- Thin surfacings such as sand seals and single seals.

At least two applications of binder are recommended for initial surfacings.

4.4.4 Quality assurance

Basic levels required: The level of quality control that could be implemented is a function of fund availability and potential risks.

However, there is no sense in specifying appropriate procedures and material properties if these are not controlled. Therefore, even if funds are limited, a quality plan should be drawn up to focus on the highest risk aspects.

Note

Testing of all bitumen properties could be expensive. Therefore, it is recommended that proper sampling be done and samples stored with limited initial control tests.

4.4.5 Labour intensive construction and impacts

Cognisance should be taken that, due to small lots, equipment used and skills differences, much higher variation in quality can be expected.

Training is required, regardless of the surfacing type to be constructed. However, the level of knowledge and skill required is dependent on the activity. For example:

- A high level of skill is required to apply binder by hand;
- A reasonable level of knowledge is required to mix the correct quantities of slurry components;
- A reasonable level of skill is required to operate a small hand-operated chip spreader;
- A lower level of knowledge and skill is required to apply sand or graded aggregate from small aggregate stockpiles;
- Spacing the stockpiles alongside the road requires a slightly higher level of knowledge.

In general it is recommended that in the case of sprayed seals, the binder should be applied by a normal binder distributor.

5 Surfacing costs

5.1 Seal cost components

5.1.1 General

The cost to construct a bituminous surfacing is often broken down into three major components namely:

- Materials;
- Equipment; and
- Labour.

Experience has shown that on a normal surfacing project the labour costs and physical cost of aggregate are small when compared to the aggregate haul costs, bitumen cost, and equipment establishment and utilisation costs. Based on information obtained from contractors, several scenarios have been calculated varying the distance from sources and the sizes of projects. The proportional distribution of costs compared with the average situation for a 13,2 mm single seal is displayed in Figure 17.

The contribution of each of these components could vary dramatically depending on:

- Size and remoteness of project;
- Haulage of suitable aggregate; and
- Constraints during construction (e.g. standing time and production rate).

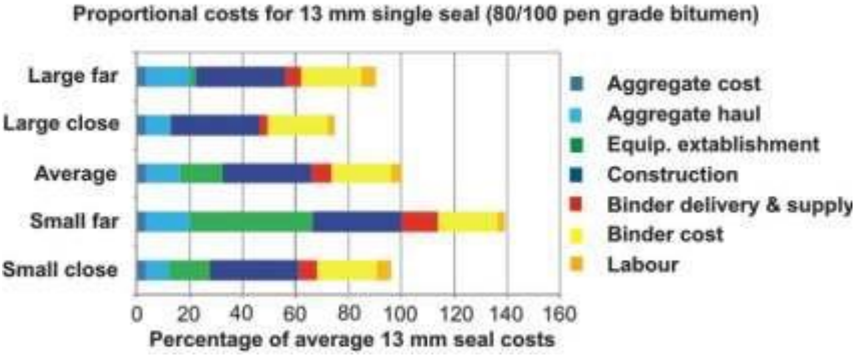


Figure 17 : Cost proportions for single seal

Note

Figure 17 does not include any provision for risk, profits or taxes.

In addition to the above (and often not elaborated on) are other activities adding to the total project costs. Examples are:

- Overheads including Contractor's provisions and requirements, safety and environmental requirements, traffic accommodation and risks;
- Consultant costs including investigation, design, quality assurance and contract administration;
- Laboratory costs;
- Cost of pre-treatment (e.g. pavement repairs);
- Line marking.

Note

Item cost for a particular seal type as tendered for in the bill of quantities, often makes up only 50% of the total project cost.

Cost ratios of other seal types, compared to a 13,2 mm single seal, are shown in Table 14.

Table 14 : Cost ratios for bituminous surfacings

Type of surfacing		Binder	Cost ratio
Single seals	13,2 mm (pre-coated)	Penetration grade bitumen	1,00
		Bitumen rubber	1,49
		Polymer modified bitumen	1,25
	13,2 mm + fog spray	Emulsion 65%	1,11
	13,2 mm + fog spray + sand	Emulsion 65%	1,52
		Latex emulsion	1,61
	9,5 mm (pre-coated)	Penetration grade bitumen	0,92
		Polymer modified bitumen	1,08
	9,5 mm + fog spray	Emulsion 65%	1,01
	9,5 mm + fog spray + sand	Emulsion 65%	1,24
		Polymer modified emulsion	1,41
	6,7 mm (pre-coated)	Penetration grade bitumen	0,60
	6,7 mm + fog spray	Emulsion 65%	0,87
Sand seals	Sand seal (single)	MC3000	0,69
		Emulsion 65%	0,73
	Sand seal (double)	MC3000	1,40
Graded aggregate seals	10 mm graded coarse sand seal	MC3000	1,16
	Single Otta and sand seal	MC3000	1,80
	Double Otta seal	MC3000	2,00
Slurry/microsurfacing	Fine slurry (3 mm)		0,87
	Coarse slurry (6 mm)		1,32
	Rapid setting coarse slurry (10 mm)		2,10
Double seals	13,2 mm + 6,7 mm	Penetration grade bitumen	1,43
		Polymer modified bitumen	1,82
	19,0 mm + 9,5 mm	Penetration grade bitumen	1,6
	19,0 mm + 6,7 mm	Split application polymer modified	2,1
	19,0 mm + 9,5 mm	Bitumen rubber	2,3
Cape seals	13,0 mm	Emulsion 65%	1,65
	19,0 mm	Emulsion 65%	2,21
Asphalt	Sand asphalt (12 mm)		2,38
	15 mm		2,55
	30 mm		3,32
	40 mm		3,90
Slurry bound Macadam	15 mm		2,55
	30 mm		3,20

Note

As shown in Figure 17 the cost of a surfacing could vary significantly due to project size, material availability and haul distances. Therefore, the cost ratio for surfacing types, relative to a 13,2 mm conventional binder seal could also vary.

In the case of graded aggregate seals, the aggregate is often obtained close to the road, resulting in a much lower cost as displayed in Table 14.

5.1.2 Bituminous binder costs

Various different binder types are available from two main suppliers in South Africa. Evaluation of binder costs over a ten year period indicates an average annual increase of 11% to 15% as shown in Figure 18 (the average increase in the cost of main binder types is approximately 13% per annum).

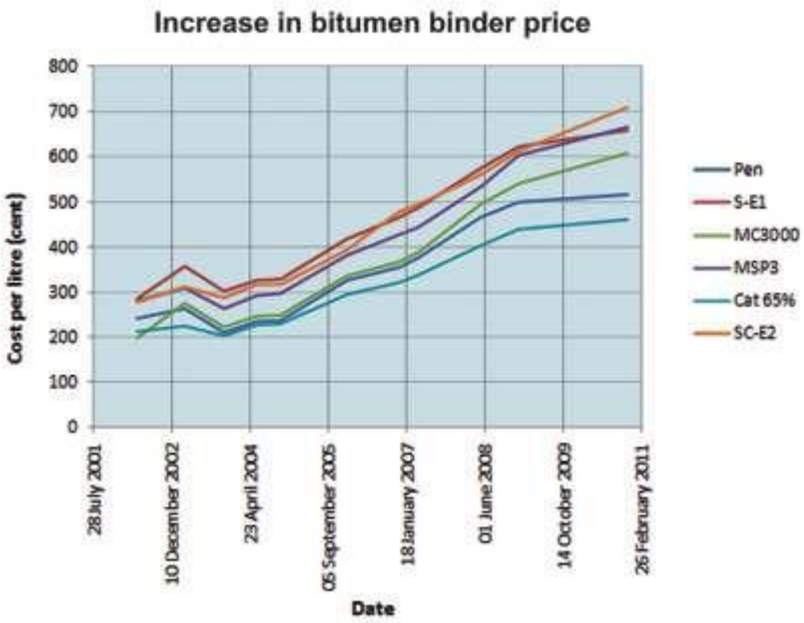


Figure 18 : Price increase of bituminous binders

Figure 18 refers to the following binder types:

Pen - 70/100 penetration grade bitumen (formerly 80/100);
S-E1 - Hot polymer modified bitumen (low polymer content);
MC3000 - Medium cut-back bitumen (approximately 12% cutter);
MSP3 - Inverted emulsion;
Cat 65% - Cationic spray grade emulsion (65% bitumen);
SC-E2 - Polymer modified emulsion .

Type: The type of binder/s to be used is determined during the investigation and design phase, but could be adjusted during construction as a result of binder availability and/or climatic conditions.

Cognisance should be taken that:

- Designs are based on the nett cold binder in the surfacing. The effective price difference per litre nett bitumen when using a cationic spray grade emulsion versus 70/100 penetration grade bitumen (formerly 80/100) could be as high as 50%;
- Modified binders are not only more expensive than conventional binders, but require more binder in the seal to prevent whip-off.

Haulage distance and application: The main binder suppliers in South Africa provide, annually or bi-annually, standard rates for different binder types, costs for delivery and cost for delivery and application, based on volume and distance of delivery. The main centres from which the binders are dispatched are:

- Johannesburg;
- Durban;
- Cape Town;
- Bloemfontein;
- Port Elizabeth;
- East London;
- Hectorspruit;
- Vryburg;
- Worcester.

Figure 19 highlights the main distribution depots in South Africa.

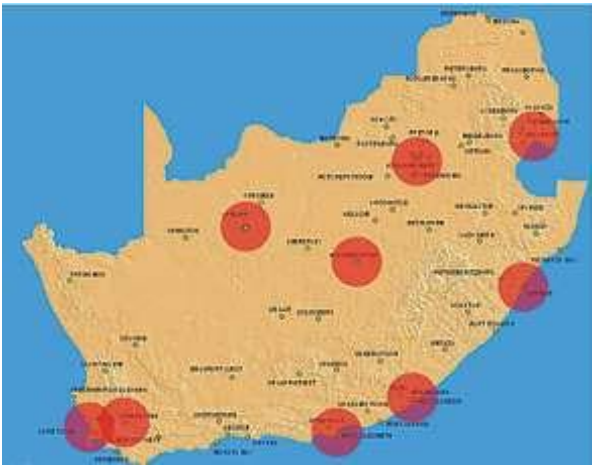


Figure 19 : Main binder depots in South Africa

Note

- Areas in orange circles define haul distances up to 50 km;
- The cost of bituminous binder could be highly influenced by the distance from main dispatch centres e.g. the delivery and spray cost (excluding the binder itself), 500 km from the depot, is double the cost of providing the binder within the 50 km radius;
- A few smaller suppliers could also be contacted for prices.

Cognisance should be taken that:

- The prices are affected by the volume of a product (binder type) ordered as follows:
  - Fixed price for 9 000 litres or less;
  - 9 000 to 14 000 litres - per litre;
  - 14 000 to 20 000 litres - per litre;
  - More than 20 000 litres - per litre.
- Using more than one binder type per seal type could add significantly to the total cost of the surfacing, especially on smaller projects.
- Construction under traffic normally results in the need to open completed sections as soon as possible. However, this could also result in smaller areas being sealed at a time with increased costs due to smaller loads/volumes being ordered at a time.

5.1.3 Aggregate costs

General: The cost of aggregate is one of the main cost components and highly dependent on the quality required and the distance of hauling.

Specifications: The higher the specifications for aggregate, the more costly the end product, both in terms of additional processing and haulage distance. Whereas it is agreed that the risk of failure and the performance of the surfacing could be compromised, there are several existing specifications (COLTO) which could be relaxed for low volume roads, as discussed in Section 4.3.2.

Haulage: The haulage cost of suitable aggregate is normally much higher than the cost of the aggregate itself as shown in Figure 17. Where possible, the use of local materials should be investigated to reduce costs.

5.1.4 Equipment and labour costs

The cost of equipment establishment and usage makes up approximately 50% of the total seal costs. Substituting equipment with hand labour could be done on very low volume roads, but does not necessarily reduce the cost of construction. Experience typically indicates an increase in the construction cost of up to 30%.

5.2 Cost-effectiveness

Cost-effectiveness could be defined in terms of the total benefits and costs over a fixed analysis period, and should include the effect on the pavement structure in terms of roughness, deterioration and extended life towards a defined terminal level.

As discussed under Section 3.3.1, the expected service life of an initial construction seal should not be penalised by a poor pavement structure. There is in fact no excuse for providing a pavement structure which cannot handle the traffic load over a short period (low volume surfaced road - suggested 10 years), (temporary deviation - suggested three months to a year).

Early failure of the bituminous surfacing - due either to the selection of an inappropriate surfacing type for the conditions at hand or to poor design and construction - is also considered unacceptable.

The appropriate initial surfacing type/s or life-cycle surfacing strategies, selected from Section 3.3 should all be cost-effective. The final selection could, therefore, be based on:

- Cost of the surfacing itself;
- Life-cycle strategy and funding availability.

In the case of temporary surfacings e.g. temporary winter seals, a texture treatment might be required before the final seal is applied. The additional pre-treatment cost should be taken into account in the surfacing selection process.

6 Maintenance planning and management

6.1 General

Any road requires maintenance in the form of:

- Routine maintenance; and
- Scheduled maintenance (reseal/resurfacing in the case of surfaced roads).

Pavements are typically designed for 20 years. Therefore, in theory, each surfaced road should be rehabilitated every 20 years (5% of the existing road network). However, with continuous routine maintenance and periodic maintenance (reseal), the service life of road pavements could be extended for many more years.

6.2 Funding requirements

Experience in southern Africa indicates that, dependent on the current condition of the surfaced road network, the cost for properly maintaining a surfaced road network varies between 2,5% and 3,5% of the pavement structure replacement value. A well maintained road network requires approximately 2,5% of the replacement value with the following distribution:

- 1% - Provision for rehabilitation;
- 1% - Provision for resurfacing;
- 0,5% - Pavement routine maintenance.

A surfaced road network in a fair to poor condition would require 3,5% or more of the pavement structure replacement value, with a typical distribution as follows:

- 1,5% - Provision for rehabilitation;
- 1% - Provision for resurfacing;
- 1% - Pavement routine maintenance.

Similar values are obtained for an annual resurfacing budget using the following assumptions:

- Average life of a seal = 10 years, requiring annual resealing of 10% of the road network;
- Using the average cost of a 13,2 mm single seal.

Note

The replacement value of the pavement structure is calculated by adding:

- Cost of all pavement layers;
- Cost of prime and multiple seal/asphalt.

6.3 Reseal selection

6.3.1 Considerations

General: Resurfacing of a road is required when the existing bituminous surfacing does not fulfil the purpose of:

- Preventing/reducing vertical moisture ingress into the pavement;
- Protecting the base from traffic wear;
- Providing sufficient skid resistance; or
- Preventing aggregate loss which can result in vehicle damage.

The selection of an appropriate reseal type or rejuvenation is highly dependent on:

- The condition of the existing surfacing and pavement structure in terms of:
    - Cracking;
    - Rutting;
    - Ravelling/aggregate loss;
    - Existing texture and variation;
    - Dryness/brittleness of the binder;
    - Softness of the existing surfacing.
- Skid resistance requirements;
- Sensitivity to damage as a result of:
    - Turning actions;
    - Shoving on steep gradients and curves;
    - Erosion due to urban drainage system;
    - Climate during or soon after construction;
- Safety and traffic accommodation requirements.

Where thin surfacings such as sand seals and thin slurries are not recommended as initial surfacings, they could be excellent options to extend the life of the existing surfacing.

These considerations are discussed in more detail in the following sections, and where relevant, the reader is referred to Section 3.3.

Existing pavement condition:

Cracking: Different crack patterns and location on the road surface provide an indication of the cause of distress. Singular line cracks more than 2 mm in width should be individually crack sealed. Crocodile pattern cracking is an indication of fatigue of the surfacing or base. If the cracks are narrow without significant pavement deformation it is still considered appropriate to reseal. However as a result of the activity of these cracks, it is normally recommended that a modified binder and/or a seal type with high binder film thickness (e.g. stone seals) be used.

Rutting: Rutting occurs mainly as a result of plastic deformation or compaction of the existing pavement layers. When the rut depth exceeds 10 mm on a crossfall of 2%, ponding of water occurs, increasing the risk of hydroplaning, but also the risk of water infiltrating into the base.

Thick surfacings such as asphalt, microsurfacings, slurry-bound macadams and thick graded seals could reduce or eliminate rutting. Alternatively, ruts could be filled as part of the pre-treatment before resealing using microsurfacing or an asphalt skim coat.

Ravelling/aggregate loss: General ravelling of aggregate occurs mainly as a result of too little binder in the surfacing structure or hardening of the binder and loss of adhesion with time. Treatments that could be considered on coarse textured surfacings are:

- Adding additional binder (diluted emulsion application, typically stable grade emulsion 50% diluted at 0,8 - 1,0 l/m^2);
- Applying a rejuvenator (high cutter content binder applied at approximately 0,4 l/m^2);
- Applying a coarse sand seal (grit) using 1,3 l/m^2 MC 3000;
- Applying a slurry seal (preferably after a diluted emulsion fogspray);
- Resealing using a small aggregate e.g. 6,7 mm;
- Using an Otta seal, microsurfacing or asphalt if warranted.

Dry/brittleness of the binder: Oxidation and hardening of the binder occurs with time, resulting in sensitivity to fatigue of the surfacing and increased permeability. Similar treatments as discussed under *Ravelling/aggregate loss* could be considered to extend the life of the surfacing and pavement.

Existing texture and variation: Variation of the surface texture transversely over the road (fine to coarse) often occurs after years of trafficking. Should the road require resurfacing as result of other defects, stone seals should not be considered without pretreatment such as a texture correction slurry.

Softness of existing surfacing: The softness of the existing surfacing could influence the performance of a new seal, especially stone seals (refer Section 3.3.1 (**Base type and quality**).

Skid requirements: Refer Section 3.3.1

Sensitivity to damage:

- Turning actions - Refer Section 3.3.1 ***(Turning actions)***;
- Shoving - Refer Section 3.3.1 ***(Steep gradients)***;
- Erosion - Refer Section 3.3.1 ***(Urban/rural drainage systems)***;
- Climate - Refer Section 3.3.1 (***Period of sealing***).

6.3.2 Selection

TRH3 Appendix D provides a decision diagram for selecting appropriate reseal types. However, it should be noted that sand seals and graded aggregate seals are not specifically mentioned. A simplified decision process for the selection of resurfacing types is provided in Table 15.

Table 15: Selection process for resurfacing

Rutting	Texture	Cracking	Recommendation
< 10 mm	Coarse or varying	Little	Sand seal, grit seal, slurry, Otta seal, combination seal, asphalt
		Severe	Texture treatment plus single seal, Otta seal, combination seal, asphalt
	Medium to fine	Little	Single seal, grit seal, sand seal, slurry, Otta seal, multiple seal, combination seal, asphalt
		Severe	Single seal, multiple seal, asphalt
> 10 mm		Little	Inverted double seal, coarse slurry, microsurfacing, asphalt
		Severe	Inverted double seal, coarse slurry, microsurfacing, microsurfacing plus single or multiple seal, asphalt

Note

- Traffic actions, volume, urban/rural drainage, contractor's ability, environment, cost etc. should be taken into account;
- TMH9 descriptions for "texture" and "degree of cracking" could be used in conjunction with TRH3 and Table 15;
- Modified binders are preferred where severe cracking occurs.

6.4 Seal maintenance

6.4.1 Fogsprays and rejuvenation

Experience in southern Africa has shown that the application of diluted emulsion or rejuvenators (proprietary products available) could extend the life of the existing surfacing by approximately 3 to 4 years. However, this is only relevant to:

- Preventing/reducing the risk of aggregate loss by adding binder;
- Temporarily reversing the ageing of the binder (softening), thereby restoring some adhesion;
- Reducing the permeability by blocking capillaries.

Products typically used are:

- Stable grade emulsions, preferably anionic, diluted 50/50 with potable water and applied at 0,8 - 1,0 l/m^2 on existing surfaces with some macro texture (e.g. 1,0 mm);
- Inverted emulsions (cut back), applied at approximately 0,4 l/m^2.

Note

Fogsprays applied when aggregate loss occurs during or soon after construction are normally cationic spray grade emulsion, applied either undiluted or diluted with less than 50% water at 0,8 - 1,0 l/m^2.

6.4.2 Surfacing repairs

Routine maintenance activities such as crack sealing, edge-break repairs and pothole repairs are essential to extend the life of the pavement. Possible early defects on the bituminous surfacing and typical repair measures are as follows:

- Stripping of aggregate:
    - This is normally stopped by application of additional binder in the form of a cationic spray grade emulsion or dilution (50/50 - 70/30 emulsion/water) and applied at 0,8 - 1,0 *l*/m^2). If significant stripping has occurred on a single seal, back-chipping could be done after applying a cationic emulsion, followed by another cover spray of cationic spray grade emulsion and application of grit (minus 4,75 mm graded sand with less than 2% dust).
- Stripping on joints:
    - A good solution is to apply cationic emulsion in the stripped joint, followed with precoated aggregate of a size smaller than the size of the stone used in the seal;
    - Alternatively, fill the stripped joint with coarse slurry. This not as neat, but is effective.
- Ravelling of small areas such as at intersections:
    - The quickest effective solution is to apply a fine or medium grade slurry over the area, obtaining in effect a Cape seal.

6.5 When to reseal and prioritisation

Different approaches and strategies could be followed to identify the need for resurfacing and to determine the priorities in case of budget limitations.

6.5.1 Economic viability

Economic viability assesses the road user benefits versus agency costs. In this regard it should be mentioned that software such as HDM4 could be used for this purpose. However, experience using economic models to identify and to optimise available funding indicates that generated road user benefits are most often too low to warrant the resurfacing on very low volume roads.

6.5.2 Preservation strategy

This strategy assumes that all surfaced roads are viable in some or other way and that the investment made should be protected by optimising the pavement performance through appropriate routine and scheduled maintenance.

Ideally the priority for resurfacing and the appropriate type of action should be based on the remaining life of the existing surfacing to fulfil its purpose (e.g. to protect the base from moisture ingress or to provide sufficient skid resistance). Where a pavement management system is in place, the remaining life could be calculated based on the rate of deterioration to an unacceptable level and the appropriate resurfacing type determined based on either a decision algorithm or effectiveness based on an "area-under-the curve method".

6.5.3 Need and priority for resurfacing

From a preservation point of view, resurfacing is required when the function of the surfacing is not fulfilled any longer. Examples are:

- Skid resistance is below acceptable limits for the conditions at hand:
  - Low macro texture;
  - Polished stone;
  - Rutting leading to ponding of water.
- The binder has hardened to such an extent that:
  - Fatigue cracking of the surfacing occurs (refer surfacing cracking TMH9);
  - Surfacing delamination occurs (refer surfacing failures TMH9);
  - Aggregate loss occurs.
- Preventing rapid pavement deterioration by:
  - Sealing fatigue cracking reflecting from the pavement structure.

The priority for resurfacing should be based on safety and extending the effective service life of the pavement structure and existing surfacing.

7 Warrants for upgrading

7.1 General

This document is not intended as a manual to evaluate the warrants for upgrading an existing unsealed road to a surfaced condition. However, feedback and comments from practitioners indicates that information required to do such calculations is not readily available for South African conditions, and that too many assumptions are made to warrant the surfacing of low volume roads.

This section describes the cost components required for economic evaluation and provides typical cost values as obtained from local road authorities and practitioners. The benefits of surfacing are then briefly discussed. The section is concluded with a discussion on available software to perform economic evaluations as well as recommendations regarding multi criteria analysis to incorporate difficult quantifiable benefits.

7.2 Cost components for economic evaluation

7.2.1 Agency costs

Life-cycle costs: The major pavement related costs expended by roads authorities to either maintain the facility as an unsurfaced road or to upgrade to a low volume surfaced road are:

- Do minimum:
  - Periodic maintenance in the form of regravelling, spot gravelling and reshaping;
  - Routine maintenance in the form of washaway repairs, pothole patching, light and heavy blading.
- Upgrade to or maintain as an engineered gravel road:
  - Construction: Upgrading to engineered gravel road by alignment changes, shaping the road bed and side drainage and add gravel to raise prism and/or add a suitable wearing course (if necessary);
  - Periodic maintenance in the form of regravelling, spot gravelling and reshaping;
  - Routine maintenance in the form of washaway repairs, pothole patching, light and heavy blading.
- Upgrade to low volume surfaced road:

- Construction: Upgrading by realignment, shaping the road bed and side drainage, add gravel to raise the road prism, add pavement layers, prime and seal;
- Periodic maintenance in the form of rejuvenation (if necessary) and reseal;
- Routine maintenance in the form of pavement and seal repairs (Refer Table 17).

Note

Proper economic analyses make use of shadow prices which exclude taxes, duties and interest charges.

Construction costs: Construction costs are highly dependent on the level to which the road is upgraded in terms of geometric standards (road width and earth works as a result of cut and fill) and cross drainage (providing structures to ensure passability).

Should the cost of major earthworks and cross drainage structures be excluded, the cost calculated for comparison includes:

- Forming and shaping the side drainage and roadbed, if necessary;
- Importing fill material to elevate the road prism above the natural ground level, if necessary;
- Additional pavement layers for structural capacity, if necessary (refer Section 2.3.1);
- Application of a prime coat;
- Application of a suitable bituminous surfacing.

Table 16 provides an indication of upgrading costs for different situations relative to the cost of a 13,2 mm single seal.

Table 16: Relative construction costs excluding bituminous surfacing

Measure	*In-situ* material condition	< 50vpd	50 - 200 vpd	200 - 400 vpd
Upgrade - existing unsealed, poor drainage	**Poor *in-situ* G8 or worse**	**4,22**	**4,44**	**4,66**
	Good *in-situ* G7 or better	**2,36**	**2,92**	**3,35**
Upgrade - existing engineered gravel road with good drainage	**Wearing course G7 or G8**	**1,09**	**1,52**	**1,96**
	Wearing course G6 or better	**0,87**	**0,87**	**0,87**

Note

- This table was compiled based on a limited number of case studies and includes prime costs but not the final bituminous surfacing;
- Costs do not represent the total project costs as traffic accommodation, Contractor's provision and general requirements, and overhead components are not included;

Example: Total costs (2011) for upgrading to a low volume surfaced road could vary significantly e.g.:

- R800 000 per km - Reshaping and compacting an existing G6 wearing course, prime and seal with a 13,2 + 6,7 mm double seal (7 m wide):
  - Example using Table 16 with R26/m^2 as cost of 13,2 mm single seal :
    - Upgrading per km , 7 m wide = 0,87 x 26 x 7 x 1000 = R 158 340
    - 13/6 double seal = 1,43 x 26 x 7 x 1000 = R 260 260
    - Sub-total = R 418 600
    - Assume sub-total = 50% of total costs
    - **Total costs per km excluding VAT = R 837 200**

- R2 200 000 per km: Form roadbed and side drainage using G9 *in-situ* material, limited vertical alignment improvement, limited additional culverts, importing two suitable pavement layers (G7 and G4 material to obtain a formation width of 8,0 m), prime and seal with a 13,2 + 6,7 mm double seal (7 m wide):
  - Example using Table 16 with R26/m^2 as cost of 13,2 mm single seal:
    - Upgrading per km , 7 m wide = 4,66 x 26 x 7 x 1000 = R 848 120
    - 13/6 double seal = 1,43 x 26 x 7 x 1000 = R 260 260
    - **Sub-total = R1 108 380**
    - Assume sub-total = 50% of total costs
    - **Total costs per km excluding VAT = R2 216 760**

- R4 500 000 per km - Upgrading an existing poor earth road, low-lying with poor drainage and poor *in-situ* material, providing culverts and low-level cross drainage structures, formation width of 9,0 m prime and seal with 19,0 mm Cape seal (7,4 m wide).

Maintenance costs: Periodic maintenance costs and annual routine maintenance costs are highly dependent on the condition of the road at that time, the appropriate minimum level to provide safe access and standards applied by the specific road authority.

Evaluation of pavement management and maintenance management information indicates the following maintenance cost components for surfaced and unsurfaced roads.

Table 17: Typical maintenance cost components

Surfaced Routine maintenance	Unsurfaced Routine maintenance
Crack sealing	Blading
Pothole/failure repair	Pothole repair
Edgebreak repair	Small washaway repairs
Undulation repair	
Shoulder blading	
Surfacing repair (slurry)	
Rest area maintenance	Rest area maintenance
Side drainage maintenance	Side drainage maintenance
Culvert cleaning	Culvert cleaning
Signs maintenance	Signs maintenance
Furniture e.g. guardrails	Furniture e.g. guardrails
Fence repair	Fence repair
Grass cutting	Grass cutting
Vegetation removal	Vegetation removal
Litter removal	Litter removal
Periodic maintenance	**Periodic maintenance**
Reseal	Regravelling
Rejuvenation	Spot gravelling
Line marking	Reshaping/reworking
Shoulder regravelling	Dust suppression
Emergency e.g. washaways	Emergency e.g. washaways
Fence replacement	Fence replacement
Structure repair	Structure repair

Whereas reasonably accurate information could be obtained for periodic maintenance activities, reported annual routine maintenance cost values for low volume roads are not necessarily reliable, the main reasons being:

- Insufficient funds available;
- Reporting systems not functional or not controlled.

Surfaced road routine maintenance: Using available information and opinions obtained from several maintenance managers, Table 18 has been compiled to serve as a rough guideline for surfaced road routine maintenance. Reported factors influencing the annual routine maintenance costs include:

- Road condition and rate of deterioration;
- Climatic conditions;
- Road purpose and importance;
- Topography/terrain;
- Distance from maintenance depot;
- Traffic.

Table 18: Annual routine maintenance costs of surfaced roads (% of 13,2 mm seal cost)

Road condition	Daily traffic	200 vpd or lower risk			200 - 400 vpd or higher risk		
	Climate	Dry	Moderate	Wet	Dry	Moderate	Wet
Poor	Total	6,2	7,0	8,2	9,2	10,5	12,4
	Pavement	5,5	6,0	6,9	8,2	9,1	10,3
Fair	Total	3,7	4,4	5,2	5,6	6,6	7,8
	Pavement	3,1	3,4	3,8	4,6	5,1	5,8
Good	Total	2,0	2,4	3,0	3,0	3,7	4,5
	Pavement	1,3	1,5	1,6	2,0	2,2	2,5

Notes

- A road to a medical clinic or school, carrying less than 200 vpd, could be classified as a higher risk road, requiring a higher standard of maintenance;
- The cost to maintain pavements in very poor condition (continuous potholing) could be much higher than indicated in Table 18;
- It is generally accepted that the higher the traffic volume, the more important the road, which therefore requires a higher standard of maintenance to reduce risks;
- It is acknowledged that much more work is required to quantify road importance and risks and to improve the provided figures;
- Value added tax (VAT) not included;
- Reported annual routine maintenance cost on the South African National Road Network (2011) varied from R40 000 per km (good condition, dry climate) to R150 000 per km (poor condition, wet climate)

Notes (continued)

Example:

The estimated required annual cost per km to maintain a very low volume 7,0 m surfaced road in a dry climatic environment, currently in a good condition is calculated as 2% of a 13,2 mm seal cost e.g.:

- 2011 cost of 13,2 mm seal = R26 per m^2. This relates to R182 000 per km for a 7,0 m wide surface;
- The annual routine maintenance cost is estimated at 2% of this value = R3 600 per km;
- The pavement related routine maintenance cost is estimated as 1,3% of R182 000 = R2 400 per km

Similarly, the required annual cost (2011) to maintain a higher order, 7,4 m surfaced road carrying 300 vpd, in a moderate climate and currently in a fair condition, is estimated at approximately R127 00 per km (6,6% x 7,4 x 1000 x R26).

Unsurfaced roads routine maintenance: Blading is considered the main routine maintenance activity on unsurfaced roads. The required blading frequency to maintain a road at an acceptable roughness level is mainly dependent on:

- Traffic volume;
- Material properties;
- Climate;
- Maintenance strategy e.g. regular reshaping and high frequency of light blading versus regular hard blading.

Notes

- The roughness deterioration model provided in TRH20 could be used to calculate the required blading frequency for a selected level of serviceability.
- The typical number of blading cycles required in the South African environment (moderate to dry climate) to maintain a roughness level IRI = 5,7, on roads with reasonable wearing course material, is as follows:
  - 50 vpd - 4 - 6 cycles;
  - 100 vpd - 6 - 10 cycles;
  - 200 vpd - 8 - 16 cycles;
  - 300 vpd - 16 - 24 cycles;
  - 400 vpd - 24 - 48 cycles.
- TRH20 recommends maximum roughness levels for different levels of serviceability;
- A road can only be properly maintained with a motor grader if sufficient material of suitable quality exists on the road;
- A minimum of four blading cycles is recommended on proclaimed unsurfaced roads.

Table 19: Comparison of IRI values and road condition

Comfortable Speed	IRI (photo)	Typical Condition
100 km/h	5 (3)	
80 - 100 km/h	7,5 5 (5,7)	
60 - 80 km/h	10 - 7,5 (8)	
45 - 60 km/h	12,5 - 10 (11)	
35 km/h	15 (15)	

Blading costs per km can vary significantly and are dependent on:

- Type of blading (light/hard, with or without moisture addition);
- Number of blading passes;
- Daily production affected by terrain/geometry, traffic volume, material/road condition, effective working hours. The typical productivity is shown in Table 20.

Table 20: Productivity (blade km per day)[31]

Maintenance measure	Easy Conditions	Moderate	Difficult conditions
Light blading	65	45	25
Hard rain blading	30	25	20
Hard blading with water truck	20	15	10

The average cost of blading (2011) varied as follows:

- Mainly light blading (40 - 60 blade km per day) - R150 - R190 per blade km;
- Mainly hard blading (10 - 25 blade km per day) - R250 and R500 per blade km.

Notes

- The majority of unsurfaced road networks in South Africa, according to Table 20, would be classified as easy to moderate maintenance conditions;
- In order to maintain the crown on an unsurfaced road of 6 - 8 m, a minimum of four blade passes is required;
- An additional pick-up blade pass is often required to obtain material to fill small irregularities;
- If the shape of the road has deteriorated e.g. no crossfall or irregularities up to 50 mm, double hard blading or complete reshaping is required;
- Dependent on the climate/rainfall and terrain/topography, maintenance of side drains and mitre drains is required between one and four times a year. Although the major part of this maintenance is done with the motor grader, significant hand work might also be required.

Therefore, the cost (2011) for blading could vary between R600 per km and R3 000 per km, with a typical average of R1 500 per km, made up of a combination of light and hard blading.

Based on available information and opinions of maintenance managers, Table 21 provides an estimation of annual routine maintenance costs for unsurfaced roads to maintain at a roughness level of IRI = 5,7.

Table 21: Annual routine maintenance costs of unsurfaced roads (% of 13,2 mm seal cost)

Traffic (ADT)	Other pavement related maintenance	Blading (maintenance conditions)		
		Easy	Moderate	Difficult
50	0,2	2,2	4,8	9,9
100	0,3	2,7	6,7	14,8
200	0,3	3,3	9,6	23,1
300	0,9	8,8	19,2	39,6
400	1,3	13,2	34,6	79,1

More frequent blading will result in a lower average roughness as shown in Figure 20.

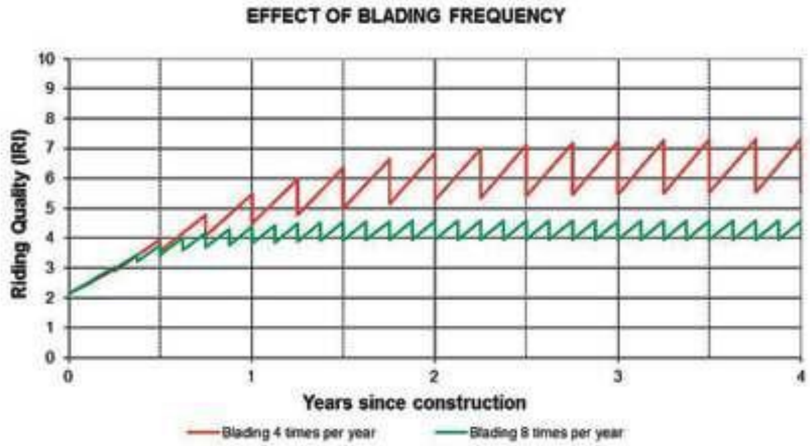


Figure 20 : Effect of blading frequency

The approximate cost ratio to maintain the riding quality at other levels, as shown in Figure 20 is shown in in Table 22.

Table 22: Cost to maintain at other roughness levels

IRI	Cost ratio
3	1,96
4	1,44
5	1,14
5,7	1,00
6	0,94
7	0,80
8	0,69
9	0,61
10	0,55
12	0,45
15	0,35

Non-pavement related routine maintenance costs are highly dependent on the standards applied e.g. whether litter is removed, fences repaired, road signs maintained or debushing occurs (vegetation removal).

Costs for this purpose (2011) on reasonably maintained unsurfaced road networks varied between R1 200 and R5 000 per km per year.

However, the opinion is held that double this expenditure would be more appropriate.

Notes

- Other pavement related maintenance includes patching and hand labour to shape culvert inlets and opening of mitre drains;
- Maintenance of side drains and mitre drains is normally done during blading operations;
- Spot gravelling, reshaping and reworking are considered periodic maintenance and therefore, not included in Table 21 as other pavement related maintenance;
- Value added tax (VAT) not included.

Example: The estimated required pavement related annual cost per km to maintain a low volume, 7,0 m wide unsurfaced road, with easy blading conditions, carrying 100 vpd at an IRI = 5,7 is calculated as 3% (0,3% + 2,7%) of a 13,2 mm seal cost e.g.:

- 2011 cost of 13,2 mm seal = R26 per m^2. This relates to R182 000 per km for a 7,0 m wide surface;
- The annual pavement related routine maintenance cost is estimated at 3% of this value = R5 460 per km.

Surfaced roads periodic maintenance: Periodic maintenance activities as noted in Table 17 should be carried out at regular intervals e.g. reseal approximately every 10 years.

The approximate cost of a specific reseal could be calculated from Table 14, taking into account that the total project cost, due to other contractual activities and overheads, is typically double that of the tendered item unit cost.

Example: The cost of a reseal on a 6,8 m wide surfaced road, using 70/100 penetration grade bitumen and 9,5 mm aggregate is calculated as follows:

- 2011 cost of 13,2 mm seal = R26 per m^2. This relates to R176 800 per km for a 6,8 m wide surface;
- Reseal cost = 0,92 x R176 800 x 2 = R325 312 per km.

Unsurfaced roads periodic maintenance: The main periodic maintenance activity on unsurfaced roads is regravelling (adding a new gravel wearing course). The frequency of regravelling is dependent on the rate of gravel loss, which is in turn, dependent on:

- Traffic volume;
- Material properties;
- Climate;
- Construction quality;
- Blading maintenance strategy.

Gravel loss models[31] typically indicate annual loss on reasonable wearing course gravel as shown in Table 23.

Table 23: Annual gravel loss (mm)

Traffic (ADT)	Climate		
	Dry	Moderate	Wet
20	4	9	13
50	7	11	14
100	13	14	15
200	24	20	19
300	35	27	22
400	47	34	26

Typical costs for periodic maintenance activities, as a percentage of a 13,2 mm single seal, are provided in Table 24.

Table 24: Periodic maintenance cost on unsurfaced roads

Periodic Maintenance Activity	Percentage of 13,2 mm single seal costs	
	Minimum	Maximum
Reshape (rip, reshape & compact wearing course 50 - 100 mm) 7,0 m	30,2	46,7
Rework (rip, break down, reshape, compact 100 mm) 7,0 m	60,4	76,9
Regravel only (125 mm) 7,0 m wide	76,9	153,8*
Spot gravelling 7,0 m wide	140,1	19,2
Forming and road bed preparation (excluding imported material)	63,2	93,4
Reforming, roadbed preparation, side drainage and regravel 150 mm	153,8	302,2*

Notes

* The high maximum costs include crushing material to minus 37,5 mm.

Example:

Regravelling (150 mm) of a 7,0 m unsurfaced road is carried out, including forming and compacting the road bed and shaping side drains, using a suitable material from a borrow pit close by (minimum scenario). The cost calculated is as follows:

- 2011 cost of 13,2 mm seal = R26 per m^2. This relates to R182 000 per km for a 7,0 m wide surface;
- Regravel project cost = 153,8% of R182 000 = R280 000 per km.

7.2.2 Road user costs

Vehicle operating costs: Assuming that the geometric alignment and specifically the gradients will not change dramatically from the unsealed road to the low volume surfaced road, vehicle operating costs are mainly influenced by the road roughness.

The International Roughness Index (IRI) is currently used for the description of road roughness (riding quality), where zero defines a perfectly smooth surface and a value of about 7,5 the upper limit for a sealed road and 10 the upper limit for an unpaved road.

The Western Cape Provincial Government (WCPG) annually publishes information on its website http://rnis.pgwc.gov.za/mis relating road roughness to vehicle operating cost (R/km) for different vehicle types. The calculation is based on a HDM-4 simplification, taking into account the cost of new vehicles, fuel, oil, tyres and labour.

The website can be accessed without password restrictions. The VOC report can be selected from the main screen, and a table of vehicle operating costs can be exported as a spreadsheet in Excel format.

Notes

- Although possible to construct a surfaced road to an IRI of 1, low volume surfaced roads tend to be constructed at IRI levels of between 2,5 and 3,5;
- If the LVSR is properly designed, constructed and maintained, the rate of roughness deterioration should be slow, providing a comfortable drive for at least 10 years;
- TRH4 recommends a terminal roughness of Present Serviceability Index (PSI) = 1,5 on category D roads (approximately IRI = 6).

Time and accident costs: Time costs and accident costs, relevant to the existing facility and intended upgraded facility, should ideally be incorporated in the economic analysis and would require investigation regarding the purpose of trips on the road and obtaining periods of impassibility and accident information.

Notes

- It might be possible that the improvement in riding quality combined with deficiencies in geometric standards during upgrading can result in an increase in the accident rate;
- Fuel consumption can also increase as a result of higher speeds.

Due to the uncertainty related to the accuracy of information on time and accident costs, and the relative low impact on the final results, no information is provided in this manual.

7.2.3 Other costs

Society costs due to impassibility (consequential costs), damage to produce transported due to roughness and health problems due to dust leading to loss of income, are site specific and should be determined through detailed investigations of a specific road.

7.3 Benefits

7.3.1 Road user benefits

Benefits are determined by calculating the difference in discounted road user cost savings due to the intended scenario (e.g. savings in time, accident and vehicle operating costs, maintaining the existing gravel road versus upgrading to a surfaced standard).

7.3.2 Social and environmental benefits

Although some of the costs to society can be quantified for different alternatives, there are numerous benefits that are not easy to quantify in monetary terms. Examples that could be used for additional motivation or incorporated into multi-criteria analysis are:

- Consequential impacts of impassibility (e.g. not being able to attend school; inability to take produce to markets to obtain best prices; access to hospitals or clinics; and visiting family and friends);
- Employment opportunities;
- Impact of dust on health, laundry, damage to crops and pollution of water sources;
- Sustainability issues such as the impact of gravel borrow pits on the environment.

7.4 Additional information required

Dependent on whether a simple economic evaluation is performed e.g. developing cost streams using Excel, or whether dedicated software is used for detailed economic evaluation, additional information might be required. This section briefly discusses information that might be required and general recommendations.

7.4.1 Analysis period

An analysis period of at least 10 years is recommended.

7.4.2 Salvage value

The relevant salvage value is dependent on the remaining life of the pavement structure or the wearing course (in the case of the unsealed road). Alternatively, a calculation could be done to determine the cost of bringing both alternatives to the same level (e.g. a new low volume surfaced road).

7.4.3 Discount rate

Information should be obtained regarding the appropriate discount rate to be applied. (Recommendations for South African conditions have varied between 8% and 10%).

7.4.4 Traffic volume and distribution

Information regarding the current traffic (light and heavy vehicles), potential attracted traffic and indication of expected annual growth rate should be obtained.

7.4.5 Life-cycle strategy

The existing maintenance strategy and the life-cycle strategy decided upon for the new facility (refer Section 3.3.1), with timing of relevant periodic maintenance.

7.4.6 Roughness and deterioration

For purposes of calculating VOC and if initial and terminal roughness levels are required, the easiest method is to assume that:

- The unsealed road will be maintained at a constant average roughness level e.g. IRI = 5,7;
- The surfaced road would deteriorate from an IRI of 2,5 - 3,5 after construction to a level of IRI = 5,7 (PSI = 1,5) after the design period.

7.4.7 Vehicle operating cost (WCPA updated link)

Using the number of heavy and light vehicles per day for each year with the corresponding roughness values as obtained from the WCPA website, the vehicle operating cost per annum could be calculated for each alternative.

7.5 Available software

7.5.1 General applicability

Three software products are available for evaluating warrants for surfacing of unsealed roads and are briefly discussed in this section in decreasing level of sophistication. The selection of the software to use should be governed by:

- Decision to invest (HDM-4 is expensive, whereas RED and SuperSurf are freely available);
- Number of projects to be evaluated - HDM-4, once set up, would be more appropriate when several projects need to be evaluated;
- Access to standardised and up-to-date information required by HDM-4 and RED;
- Available skills (trained staff) as HDM-4 is the most complex tool.

Upgrading of low volume roads to a surfaced standard is often found to be not viable from an economic viewpoint. One of the main reasons is the difficulty to quantify other benefits in terms of economic parameters. Section 7.6 provides some guidelines in this regard.

7.5.2 Highway Development and Management software (HDM-4)

The HDM-4 software, initially developed by the World Bank and subsequently improved, is the most comprehensive set of tools developed to evaluate the impact of road investments. It can be used for:

- Strategic analysis;
- Programme analysis; and
- Project analysis.

Project analysis may be used to estimate the economic or engineering viability of road investment projects by considering the following issues:

- The structural performance of road pavements;
- Life-cycle predictions of road deterioration, road works and costs;
- Road user costs and benefits;
- Economic comparisons of project alternatives;
- Preservation of the road network's asset value;
- Sensitivity of a road project measured by technical and economic indicators to changes in one parameter;
- Viability of a road project when the road project is subjected to a broad range of input scenarios.

Typical appraisal projects would include the maintenance and rehabilitation of existing roads, widening or geometric improvement schemes, pavement upgrading and new construction.

The technical and economic assessment of road investment projects does not explicitly consider social, political and environmental aspects of road investments, and does not necessarily correctly reflect the desired priorities for investments by all stakeholders. The use of multi criteria analysis as discussed in Section 7.6 is therefore recommended to augment the outputs of HDM-4.

The set-up and use of HDM-4 requires a good knowledge of the software itself as well as regular updating of data sets (e.g. vehicle fleet information, work standards, costs and calibration factors).

Some provincial road authorities in South Africa (e.g. Western Cape Provincial Government) undertake annual updates, which could be made available on request.

7.5.3 Roads Economic Decision model (RED)

RED is a consumer surplus model designed to help evaluate investments in low volume roads. The model, which is based on HDM, is much easier to use and can be implemented in a series of Excel workbooks that:

- Collect all user inputs;
- Present the results in a user-friendly manner;
- Estimate vehicle operating costs and speeds;
- Perform an economic comparison of investments and maintenance alternatives; and
- Perform sensitivity, switch-off values and stochastic risk analyses.

The model computes benefits accruing to normal, generated, and diverted traffic, as a function of a reduction in vehicle operating and time costs. It also computes safety benefits, and users can add other benefits (or costs) to the analysis, such as those related to non-motorised traffic, social service delivery and environmental impacts.

The RED model was funded by the Sub-Saharan Africa Transport Policy Programme (SSATP), which is a collaborative framework set up to improve transport policies and strengthen institutional capacity in the Africa region. It is freely available and can be downloaded from the following website: http://www4.worldbank.org/afr/ssatp/Resources/HTML/Models/RED_3.2/red32_en.htm.

Apart from the project details the model requires relevant vehicle fleet data, costs and appropriate calibration factors.

7.5.4 SuperSurf

Background: SuperSurf was developed in 2004 primarily for the analysis of various upgrading options for low volume roads, specifically from gravel to sealed standard incorporating appropriate standards for these roads.
If a sealed road is to be economically competitive with an unsealed road, the total cost of construction, maintenance, rehabilitation and operation over the design life (or analysis period) of the road needs to be lower than that of the equivalent unsealed road. As the road user costs typically dominate such economic comparisons, the main economic benefits of sealed roads over unsealed roads are provided by the reduced vehicle operating costs that accrue from the improved riding quality of the sealed road over the unsealed road.

It is thus essential that the cost of constructing the sealed road be as low as possible to offset the cost benefit of the improved riding quality against the construction cost, bearing in mind that the riding quality of the sealed road needs to be significantly better than that of the unsealed road. In other words, a reduction of quality standards in the sealed road leading to a poor riding quality would not result in any measureable benefit over a well-maintained unsealed road.

It is well-known and repeatedly noted that the availability of good wearing course gravels for unsealed roads is diminishing rapidly. This lack of good material leads to poorer riding quality developing more rapidly, increased maintenance costs and thus a rapid increase in the total life-cycle costs of the road. At the same time, more and more work is being carried out in the field of sustainability, specifically related to non-renewable resources, of which wearing course gravels are a major one.

A typical gravel road requires about 1 350m^3 of gravel per kilometre during regravelling. This would usually last for between five and nine years before it is worn away by traffic, eroded by water or lost as dust. Replacement of this gravel involves a significant cost, disruption to traffic flows, safety hazards and environmental degradation.

Although recent work has shown that by selecting the best materials that comply with the specification for wearing course gravel (TRH20, 2009) and ensuring that the layer is constructed to the specified requirements and the gravel loss can be significantly reduced, sustainability and negative environmental impacts persist. By sealing the wearing course the material will be preserved for reuse.

Although SuperSurf contains a facility to adjust the fixed input costs by an equivalent inflation value, some of the models may not necessarily be affected by equal inflation increases (e.g.the price of fuel and bitumen may increase more rapidly than the average inflation rate). The models predicting road user costs from road roughness are also being improved and updated regularly. Although the macros in SuperSurf are password protected to prevent uninformed users from modifying them, the facility does exist to modify and update these where necessary.

Information required: The input data necessary for running SuperSurf is similar to that required for any cost optimisation model. This includes:

- Total traffic numbers (split between heavy and light or individual counts for car, LDV, taxi, bus, MGV and HGV), year of count and growth rates;
- Gravel road maintenance costs, blading, gravel, other routine, dust palliation;
- Paved road construction costs, maintenance (reseal, routine, overlay) and preferred design/maintenance strategy;
- Climatic region;
- Unpaved road material properties (TRH20), thickness, desired riding quality range and road width;
- Various inputs necessary for calculation of social and environmental costs/benefits.

As little data is usually available for the calculation of social and environmental benefits, the facility exists in SuperSurf to determine a break-even point at which these costs can be related to the actual situation, and a decision made as to whether the figures calculated can be justified on social or environmental grounds.

7.6 Multi Criteria Analysis (MCA)

Multi criteria analysis, as described in HDM-4 documentation, provides a systematic framework for breaking a problem into constituent parts in order to understand the problem and consequently arrive at a decision. It provides a means to investigate a number of choices or alternatives, in light of conflicting priorities. By structuring a problem within the multiple criteria analysis framework, road investment alternatives may be evaluated according to pre-established preferences in order to achieve defined objectives.

MCA requires clear definition of possible alternatives, together with the criteria under which the relative performance of the alternatives in achieving the pre-established objectives is to be measured. Thereafter it requires the assignment of preference (i.e. a measure of relative importance or weighting) to each of the criteria.

Table 25 shows the criteria supported in HDM-4 multi criteria analysis. However, the objectives for upgrading of a specific road or roads within a specific area could be different.

Table 25 : Criteria supported in HDM-4 multi criteria analysis

Category	Criteria/objectives	Attributes
Economic	Minimise road user costs (RUC)	Total road user costs are calculated internally within HDM-4 for each alternative.
	Maximise net present value (NPV)	Economic net benefit to society is calculated internally within HDM-4 for each alternative.
Safety	Reduce accidents	Total number and severity of road accidents, calculated internally within HDM-4.
Functional service level	Provide comfort	Provide good riding quality to road users. This is defined on the basis of average IRI (international roughness index). The average IRI is calculated internally within HDM-4.
	Reduce road congestion	Delay and congestion effects. Level of congestion is defined in terms of volume capacity ration (VCR). VCR values are calculated internally within HDM-4.
Environment	Reduce air pollution	Air pollution is measured in terms of quantities of pollutants from vehicle emissions, which are calculated internally within HDM-4.
Energy	Maximise energy efficiency	Efficiency in both global and national energy use in the road transport sector. Energy use is calculated internally within HDM-4.
Social	Maximise social benefits	Social benefits include improved access to social services, e.g. schools, health centres, markets etc. A representative value is externally user-defined for each alternative.
Political	Consider political issues	Fairness in providing road access, promotion of political stability, strategic importance of roads etc. A representative value is externally user-defined for each alternative.

It is recommended that objectives and weighting be established with all stakeholders. A practical method to obtain comparable values is to force the summed weighting to equal 1.

The attributes of each alternative (e.g. maintain as gravel road, upgrade to low geometric standard or upgrade to high geometric standard) is then determined and rated/measured according to the ideal situation with the maximum (ideal) value equal to 1.

By multiplying the weighting for each category with the measure to which the specific alternative is rated relative to the ideal situation and then calculating the sum of all category values, a maximum score of 1 could be obtained. The principle is shown in Figure 21.

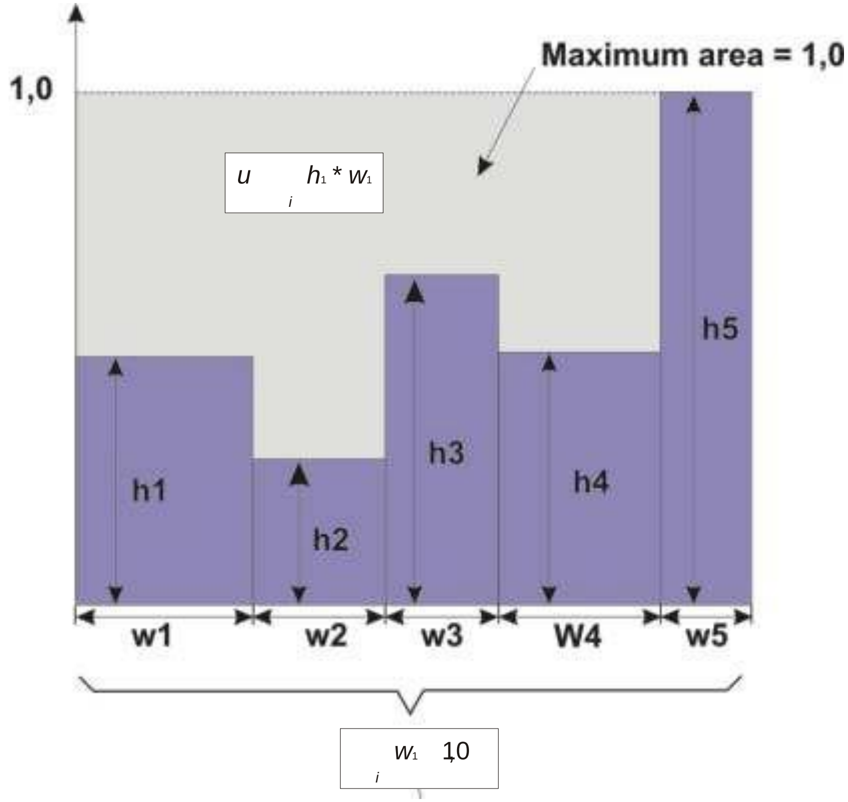


Figure 21 : Principle of multi criteria analysis

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Appendix A

Notes, examples and performance ratings of different surfacing types

Introduction

The purpose of this Appendix is to highlight different surfacing types used on low volume roads with comments as received from various practitioners.

Surfacings addressed are:

- Asphalt:
  - Hot mix;
  - Warm mix asphalt;
  - Cold mix asphalt;
  - 30 - 50 mm continuously graded;
  - Thin asphalt (12 - 20 mm);
  - Sand asphalt.
- Cape seals;
- Graded aggregate and sand seals:
  - Otta seals;
  - Coarse graded sand seals;
  - Thin sand seals and dust palliatives.
- Double seals;
- Single seals with and without sand/grit blinding;
- Slurry and microsurfacing;
- Slurry-bound Macadam.

It should be noted that examples were found of all surfacing types performing well and poorly, and that the main reasons for poor surfacing performance were either poor base construction and finish, or insufficient quality control during surfacing construction.

As shown in the photographs below, surfacing failures are already occurring on a brand new, but poorly constructed base.

The performance rating provided is based on the risks of poor performance from the original Sabita study, new observations and practitioner feedback and does not necessarily agree with the opinions of the authors.

Hot mix asphalt (HMA): HMA provides excellent performance under almost all conditions. However, it requires an asphalt plant nearby and good quality control. While it has a relatively high construction cost, it gives good life-cycle costs and is, generally maintenance free. Performance is poor if placed on a weak pavement structure. It is excellent for urban roads and the smooth appearance gives an image of a high quality surfacing. Good for areas where the road forms a large part of the habitat. Also good if the road is used as a playground.

30 mm asphalt on steep grades >20 years

Smooth surface effective as playground

30 mm asphalt on steep grades. Water and chemical erosion measured at 5 mm/annum

40 mm asphalt effective in preventing damage due to building rubble

Numerous low volume roads and urban streets in the Western Cape have been surfaced or resurfaced with ultra thin asphalt (12 mm). The only negative observation is the very smooth surface (low macro texture and potential skid resistance problem) due to a very fine aggregate grading (typically less than 4,75 mm).

12 mm UTA initial surfacing residential street

12 mm UTA resurfacing low speed rural road

The tables on the following pages examine the performance ratings for a variety of seals and mixes, performing under a variety of different conditions. The colours in the legend below indicate the surfacing type recommended by practitioners based on experience.

🟩	**Majority of practitioners indicate suitability of the particular type of surfacing in the specific cell.**
🟨	**One of two practitioners indicated good experience of the surfacing type in this situation. However, not generally recommended by others.**

30 - 50 mm continuously graded hot mix asphalt

	Performance rating				
Road gradient constructability	< 6%	6 - 8%	8 - 12%	12 - 16%	> 16%
Sensitivity to urban drainage	Very high	High	Medium	Low	Very low
Sensitivity to poor base finish	Very high	High	Medium	Low	Very low
Performance under turning actions	Very poor	Poor	Medium	Good	Very good
Sensitivity to maintenance capability	Very high	High	Medium	Low	Very low
General risk rating	Very high	High	Medium	Low	Very low
Suitability for labour based methods	Very poor	Poor	Medium	Good	Very good
Additional notes					
Hot mix asphalt	Haulage distance recommended < 150 km				
Warm mix asphalt	Haulage distance recommended < 600 km Small aggregate mixes (9,5 mm) could be quite effective for labour intensive construction				
Cold mix asphalt	Problems with poor compaction result in porous surfacing Effective for labour intensive work				

Thin asphalt (12 - 20 mm)

	Performance rating				
Road gradient constructability	< 6%	6 - 8%	8 - 12%	12 - 16%	> 16%
Sensitivity to urban drainage	Very high	High	Medium	Low	Very low
Sensitivity to poor base finish	Very high	High	Medium	Low	Very low
Performance under turning actions	Very poor	Poor	Medium	Good	Very good
Sensitivity to maintenance capability	Very high	High	Medium	Low	Very low
General risk rating	Very high	High	Medium	Low	Very low
Suitability for labour based methods	Very poor	Poor	Medium	Good	Very good
Additional notes	Sensitive to steep grades and turning actions on smooth base Quality of product strongly dependent on producer				

Sand asphalt (12 - 20 mm)

	Performance rating				
Road gradient constructability	< 6%	6 - 8%	8 - 12%	12 - 16%	> 16%
Sensitivity to urban drainage	Very high	High	Medium	Low	Very low
Sensitivity to poor base finish	Very high	High	Medium	Low	Very low
Performance under turning actions	Very poor	Poor	Medium	Good	Very good
Sensitivity to maintenance capability	Very high	High	Medium	Low	Very low
General risk rating	Very high	High	Medium	Low	Very low
Suitability for labour based methods	Very poor	Poor	Medium	Good	Very good
Additional notes	Sensitive to shoving on steep grades and tight curves No record of any sand asphalt placed during the past ten years				

Cape seals: Good performance under most conditions. However, good construction quality is vital. The smooth appearance gives an image of a high quality surfacing. Good for areas where the road forms a large part of the habitat, or is used as a playground. It is a relatively stiff surfacing which can cause problems with weak pavement layers.

19 mm Cape seal older than 15 years

Oxidation/hardening of the binder and fine cracking identify the need for resurfacing

9,5 mm Cape seal on intersection (after 9 years)

	Cape seals				
					Performance rating
Road gradient constructability	**< 6%**	**6 - 8%**	**8 - 12%**	**12 - 16%**	**> 16%**
Sensitivity to urban drainage	**Very high**	**High**	**Medium**	**Low**	**Very low**
Sensitivity to poor base finish	**Very high**	**High**	**Medium**	**Low**	**Very low**
Performance under turning actions	**Very poor**	**Poor**	**Medium**	**Good**	**Very good**
Sensitivity to maintenance capability	**Very high**	**High**	**Medium**	**Low**	**Very low**
General risk rating	**Very high**	**High**	**Medium**	**Low**	**Very low**
Suitability for labour based methods	**Very poor**	**Poor**	**Medium**	**Good**	**Very good**
Additional notes	**High binder content > 10% improves performance of the seal Construction at grades depends on binder viscosity**				

Graded aggregate and sand seals - Otta seals and thick graded aggregate seals (16 - 20 mm): Excellent performance in general, especially for rural environments if a thick or double application is used (sand cover seal). It is suitable for labour intensive construction provided the binder is applied with a distributor. A soft binder and high fines content is recommended. Constraints recorded in South Africa in attempting to obtain approval to open shallow borrow pits for the aggregate.

Double Otta seal older than 20 years

Thick single Otta seal (>15 mm) with high fines content

Minus 13 mm single Otta seal (after 8 years)

Small surfacing failures identify the need for resurfacing

Graded aggregate seal (minus 13,2 mm with low fines content) after 8 years

Aggregate loss and small surfacing failures identify the need for resurfacing

Thick graded aggregate and Otta seals					
	Performance rating				
Road gradient constructability	< 6%	6 - 8%	8 - 12%	12 - 16%	> 16%
Sensitivity to urban drainage	Very high	High	Medium	Low	Very low
Sensitivity to poor base finish	Very high	High	Medium	Low	Very low
Performance under turning actions	Very poor	Poor	Medium	Good	Very good
Sensitivity to maintenance capability	Very high	High	Medium	Low	Very low
General risk rating	Very high	High	Medium	Low	Very low
Suitability for labour based methods	Very poor	Poor	Medium	Good	Very good
Additional notes	Sensitive to urban drainage during early life as a result of sand blocking drainage system Single Otta seals or low fines content graded seals require reseal much earlier Recommended that binder be applied by distributor				

Coarse graded sand seals (8 - 10 mm): Good to poor performance recorded as initial seals. Sensitive due to one binder application and related risk of poor transverse distribution or blocked nozzles. Soft binder and high fines content recommended.

Coarse graded sand seal (minus 10 years

10 mm with low fines content) after irregularities in base

Several surfacing failures occur and seal too thin to accommodate

Coarse graded sand seals					
	Performance rating				
Road gradient constructability	< 6%	6 - 8%	8 - 12%	12 - 16%	> 16%
Sensitivity to urban drainage	Very high	High	Medium	Low	Very low
Sensitivity to poor base finish	Very high	High	Medium	Low	Very low
Performance under turning actions	Very poor	Poor	Medium	Good	Very good
Sensitivity to maintenance capability	Very high	High	Medium	Low	Very low
General risk rating	Very high	High	Medium	Low	Very low
Suitability for labour based methods	Very poor	Poor	Medium	Good	Very good
Additional notes	Sensitive to urban drainage during early life as a result of sand blocking drainage system Performance at intersections could be improved by maintaining loose fine sand layer Soft binders and high fines content improve performance				

Thin sand seals and dust palliatives: Fair to poor performance as initial seals - more of a temporary surfacing and vital to reseal timeously before maintenance costs rise. Not suitable for low maintenance environments.

Thin sand seal (6 mm) after 8 years

Disintegration of surfacing at intersection within 6 months

Dust palliative resealed after 3 years with 9,5 mm single seal (20 years later)
10 years

No defects apart from dry and brittle binder

irregularities in base

Thin sand seals and bituminous dust palliatives					
	Performance rating				
Road gradient constructability	< 6%	6 - 8%	8 - 12%	12 - 16%	> 16%
Sensitivity to urban drainage	Very high	High	Medium	Low	Very low
Sensitivity to poor base finish	Very high	High	Medium	Low	Very low
Performance under turning actions	Very poor	Poor	Medium	Good	Very good
Sensitivity to maintenance capability	Very high	High	Medium	Low	Very low
General risk rating	Very high	High	Medium	Low	Very low
Suitability for labour based methods	Very poor	Poor	Medium	Good	Very good
Additional notes	Sensitive to urban drainage during early life as a result of sand blocking drainage system Very sensitive to turning actions and low maintenance capacity				

Double seals and single seals with sand/grit blinding: Good performance in rural areas and fair performance in urban areas. The seals need at least 50 vpd to keep the binder alive. The use of sand/grit as the second application of aggregate (in an engineered application with a second spray of binder) has the advantage that the sand reduces the sensitivity to aggregate loss, but increases the stiffness of the surfacing.

Single 9,5 mm seal with sand after 9 years

Small surfacing failures occur

13,2 plus 6,7 mm double seal after

No defects apart from dry and brittle

13,2 mm plus grit double seal after 6 years

No defects

13,2 mm plus high fines sand seal after 6 years. Labour intensive construction

No defects apart from fattiness

13,2 mm plus 6,7 mm double seal after 3 years on steep grade in urban developing area. Soil wash and high

10 years *binder*

speed water eroded the stone seal. No maintenance

Double seals/single plus sand					
	Performance rating				
Road gradient constructability	< 6%	6 - 8%	8 - 12%	12 - 16%	> 16%
Sensitivity to urban drainage	Very high	High	Medium	Low	Very low
Sensitivity to poor base finish	Very high	High	Medium	Low	Very low
Performance under turning actions	Very poor	Poor	Medium	Good	Very good
Sensitivity to maintenance capability	Very high	High	Medium	Low	Very low
General risk rating	Very high	High	Medium	Low	Very low
Suitability for labour based methods	Very poor	Poor	Medium	Good	Very good
Additional notes	Construction at grades depends on binder viscosity Much better performance when emulsion cover spray is applied on top layer aggregate Grit or sand in top layer reduces risk of aggregate loss Successful application of aggregate has been introduced using hand-operated equipment (e.g. Chippie).				

Single seals without sand/grit blinding: Gives fair to poor performance as an initial seal, mainly due to only one application of binder and related

13,2 mm single seal after 11 years on properly constructed base

Aggregate loss evident

13,2 mm single seal after 25 years on properly constructed base and with high application rate

No defects apart from brittle binder

13,2 mm single seal after 3 years. Binder content too low and construction defects evident

Aggregate loss on single seal due to turning actions

risks of nozzle blockage. The seals are highly sensitive where turning actions occur and/or in urban drainage situations.

Single seals					
	Performance rating				
Road gradient constructability	< 6%	6 - 8%	8 - 12%	12 - 16%	> 16%
Sensitivity to urban drainage	Very high	High	Medium	Low	Very low
Sensitivity to poor base finish	Very high	High	Medium	Low	Very low
Performance under turning actions	Very poor	Poor	Medium	Good	Very good
Sensitivity to maintenance capability	Very high	High	Medium	Low	Very low
General risk rating	Very high	High	Medium	Low	Very low
Suitability for labour based methods	Very poor	Poor	Medium	Good	Very good
Additional notes	Construction at grades depends on binder viscosity; Much better performance when emulsion cover spray is applied Highly sensitive to turning actions; Successful application of aggregate has been introduced using hand-operated equipment (e.g. Chippie).				

Slurry and microsurfacing: These surfacings generally give fair performance if thick, and poor performance if thin (<8 mm) when used as an initial surfacing. Conventional slurry is vulnerable to pedestrian and vehicle traffic if fresh. Irregularities on the new base could lead to areas with a very thin layer. Slurry should be applied in two layers, each at least 6 mm thick.

Quick-set slurries and microsurfacings are very useful where road closure time is limited, or in shade or cool weather. It is a stiff layer and sensitive to weak pavement layers. The smooth appearance gives an image of a high quality surfacing. Good for areas where the road forms a large part of the habitat. Also good if the road is used as a playground.

Base damage due to trafficking

Microsurfacing applied (minimum 8 mm) allowed quick opening to traffic and can serve as initial seal for several years

Thick rapid setting slurry and microsurfacing (>10 mm)

	Performance rating				
Road gradient constructability	**< 6%**	**6 - 8%**	**8 - 12%**	**12 - 16%**	**> 16%**
Sensitivity to urban drainage	**Very high**	**High**	**Medium**	**Low**	**Very low**
Sensitivity to poor base finish	**Very high**	**High**	**Medium**	**Low**	**Very low**
Performance under turning actions	**Very poor**	**Poor**	**Medium**	**Good**	**Very good**
Sensitivity to maintenance capability	**Very high**	**High**	**Medium**	**Low**	**Very low**
General risk rating	**Very high**	**High**	**Medium**	**Low**	**Very low**
Suitability for labour based methods	**Very poor**	**Poor**	**Medium**	**Good**	**Very good**
Additional notes	**Recommended maximum 10% grade** **Excellent to improve base irregularities but sensitive to loose, uncompacted material**				

Thin conventional slurry (<6 mm)

	Performance rating				
Road gradient constructability	**< 6%**	**6 - 8%**	**8 - 12%**	**12 - 16%**	**> 16%**
Sensitivity to urban drainage	**Very high**	**High**	**Medium**	**Low**	**Very low**
Sensitivity to poor base finish	**Very high**	**High**	**Medium**	**Low**	**Very low**
Performance under turning actions	**Very poor**	**Poor**	**Medium**	**Good**	**Very good**
Sensitivity to maintenance capability	**Very high**	**High**	**Medium**	**Low**	**Very low**
General risk rating	**Very high**	**High**	**Medium**	**Low**	**Very low**
Suitability for labour based methods	**Very poor**	**Poor**	**Medium**	**Good**	**Very good**
Additional notes	**Recommended maximum 10% grade** **Excellent to improve base irregularities but sensitive to loose, uncompacted material**				

Slurry-bound Macadam: Very good to good performance recorded. Problems mainly related to the construction quality and control. It is excellent for labour intensive work but is slow to construct.

Slurry-bound Macadam					
	Performance rating				
Road gradient constructability	< 6%	6 - 8%	8 - 12%	12 - 16%	> 16%
Sensitivity to urban drainage	Very high	High	Medium	Low	Very low
Sensitivity to poor base finish	Very high	High	Medium	Low	Very low
Performance under turning actions	Very poor	Poor	Medium	Good	Very good
Sensitivity to maintenance capability	Very high	High	Medium	Low	Very low
General risk rating	Very high	High	Medium	Low	Very low
Suitability for labour based methods	Very poor	Poor	Medium	Good	Very good
Additional notes	Quality control very important Slow progress				