The World Bank

Surfacing Alternatives for Unsealed Rural Roads

September 2005

MWH

Acknowledgements:
This report was sponsored by the Transport and Rural Infrastructure Services Partnership (TRISP). TRISP-DFID/ World Bank Partnership for learning and sharing knowledge.

The author also acknowledges the significant input from the review panel during the compilation of these guidelines.

Quality Assurance Statement	
The World Bank **Surfacing Alternatives for Unsealed Rural Roads**	**Prepared by:** Henning, Kadar and Thew **Reviewed by:** C.R. Bennett, R.C. Petts, A.T. Visser, D. Jones and G. Giummarra
Project Manager: Theuns Henning	**Approved for issue by:** Theuns Henning *September 2005 – Z092780*

Revision Schedule					
Rev. No	Date	Description	Prepared by	Reviewed by	Approved by
1	24 Feb 05	Incorporated reviewers comments	TH	TK	TH
2	30 Aug 05	Incorporate World Bank Comments	PK, TH		TH
3	21 Sept. 05	Incorporate additional World Bank Comments	TH	CRB	TH

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1. Introduction

1.1 Background to the Project

Around the world road networks are the vital arteries of societies. The need for roads to provide safe and comfortable access and thus contribute to the economical sustainability and environmental protection has been increasing with time. Over the last century there has been a dramatic increase in the proportion of paved roads due to the increased comfort and reliability provided by concrete and bituminous surfaces. Whilst the length of sealed roads increased, the importance of unsealed or unpaved roads was often overlooked. In fact the vast majority of the network will remain unsealed in most developing and emerging economies for some time to come. As for all economies, the adequate maintenance of the road network is paramount for socio-economic development. For most developing and emerging economies, the road maintenance challenge is dominated by the maintenance of unsealed roads.

Over the years, engineers have become knowledgeable at optimising resources for maintaining unsealed roads. Numerous manuals and guidelines have been produced, mostly for developed countries with extensive unsealed networks. Some examples include: ARRB (2000), Ferry (1986) and Visser, et al. (1994). Most of these manuals also touch on principles underlying the decision to upgrade from unsealed to paved surfaced roads. Some manuals include adopting innovative construction and maintenance for the surface layer of unsealed roads.

The manuals produced by developed countries generally have some sections that may be inappropriate for developing countries where the socio-economics, traffic and climatic conditions are different. However, guidelines and literature in these areas are scarce and there is very little information available that summarises the experience with unsealed roads around the world. The intent of this document is to provide network managers with a brief summary of international practice based on a literature review, a questionnaire distributed amongst practitioners and some case studies on related topic areas. Based on this input a decision framework was developed to assist the network manager in selecting the most appropriate surfacing option for unsealed roads according to a range of factors and circumstances.

1.2 Objectives

The objectives, as stated in the Terms of Reference for the project, is to *prepare a concise report which represents the full range of options for rural road surfacing, supported by a framework to assist decision makers.* It is also recognised that the engineering objectives need to be balanced against other issues that included:

- availability of funds
- availability of materials;
- cost effectiveness;
- road function;
- traffic volumes and composition;

- practitioners training and experience;
- user needs and expectations; and,
- availability of technology.

The outcome of this report will assist in the decision making for the most appropriate surfacing selection, given a range of issues and constraints.

1.3 Scope of the Report

The report covers four main areas including:

- A summary of international experience in maintaining unsealed roads. The emphasis is placed on the critical factors in selecting an appropriate surfacing option for different situations;
- Case studies are summarised to give an indication of the performance of different technologies. The applicability of each option is discussed for given circumstances. The case studies discussed include performance studies of unsealed roads, case studies of dust palliatives and a summary of some alternative surfacing technologies;
- The results of a questionnaire are discussed (See Appendix D). The questionnaire was developed to ascertain common practice and the factors considered during the surfacing options selection process; and,
- Based on the input of the previous points, a decision framework was developed that assists the reader in selecting the most appropriate surfacing according to a range of factors and circumstances.

Part 1 – Background to Unsealed Roads and International Practice

2. Review of International Experience with Unsealed Roads

Unsealed roads are a critical and substantial part of most of the entire rural road networks in both the developed and developing countries. For example, in some developed countries, up to 60 per cent of the network can be unsealed. The percentage is usually higher in developing and emerging economies. The maintenance of unsealed roads is an essential function, particularly where these roads form the backbone of the local land transportation system. As unsealed roads are typically maintained locally, the use of materials and technologies can vary widely. The following is a conceptual summary of the available practices/technologies:

2.1 Terminology

Unsealed roads are also referred to as unpaved roads. Though it is a matter of convention what is considered a pavement, for the purpose of this document all roads without a permanent waterproof surface will be considered unsealed. These include engineered and un-engineered roads.

2.1.1 Unformed roads

Unformed roads, also referred to as earth roads, have a natural alignment on the terrain without any engineering input. These roads typically evolve from local tracks. Unformed roads have no drainage, cross fall, added granular material or other features that would ensure all-weather access. Unformed roads are most common when the dominating traffic is animal driven, low speed or light motorised.

2.1.2 Formed roads

Formed roads usually have a reasonably well defined cross section, including drainage. The road formation reflects the desire to cater for vehicular traffic of reasonable speed in most weather conditions. Usually these roads consist of locally available earth material with no added surfacing material.

2.1.3 Gravelled roads

A more appropriate name for gravel roads would be "gravelled and formed" roads as these roads should be built and designed to certain engineering principles, including the importation, where warranted, of gravel wearing surface. Construction of these roads also involves a defined cross section, drainage and structures (bridges, culverts).

Gravelling is also considered a pavement, as it usually increases the load bearing capacity of the road. Gravel roads allow the safe and fast passage of heavy vehicles. Regravelling is a major maintenance function, required to replace surface material losses due to rainfall, traffic and dust. The term "Gravel" includes natural occurring materials such as laterites, and well graded crushed stone for the purpose of this document.

2.1.4 Sealed roads

Roads with all-weather dust-free surface belong to the sealed roads category. Seal covers a wide range of technologies from bitumen seal to thin (not load bearing) asphalt surfacing.

Sealed roads represent a qualitative change in terms of road construction and maintenance as well as service level. Sealed roads typically allow vehicular speed in excess of 60 km/h and are primarily built for motorised vehicle traffic. Road are also often sealed for other socio economic reasons such as providing even surface for no-motorised vehicles and improving environmental conditions in populated areas. The selection of the type of surface under these conditions is often a function of the primary reason for sealing. For example, with the provision of a sealed road in urban areas smoother surfaces are normally used for comfort reasons of non-motorised. Sealed roads also require a different maintenance regime, as:

- Maintenance is required to protect the sealed initial investment; and,
- Specialised technologies, skills and materials are required, as opposed to the local resources often available for unsealed roads.

The current document is focused on the issues involved in the transition from unsealed to sealed roads. These include the questions of "when" and "how". This chapter addresses the available technologies to make this step. To place the surfacing options in their context, all relevant maintenance activities will be briefly discussed. The rationalisation and decision making aspects will be addressed in the following chapter.

2.2 Failure Modes of Unsealed Roads

Unsealed roads have often developed over time by following the tracks of local traffic or unformed roads. Consequently the alignment, cross-section, and drainage may not necessarily be suitable for motorised traffic. Maintenance of unsealed roads is different from that of sealed roads, as maintaining the road in its original condition may not be desirable at all for the former. As the gradual evolution of the unsealed road often did not always allow for proper engineering input, maintenance and gradual upgrading of facilities tend to overlap.

A good understanding of failure modes contributes to the selection of the most appropriate treatments. By addressing the true cause of the road failure, the problem can be resolved for the long term, whilst addressing the symptoms will usually yield short term solutions - hence the importance of being able to distinguish between the cause and symptom. Some surfacing options may not necessarily address the failures associated with the unsealed road. For example, dust palliatives could be effectively addressing dustiness but will not address poor ride due to over sized rocks in wearing course.

Unformed roads are particularly prone to structural and surface failures due to the fact that unformed roads have no inherent engineering considerations, hence have the least resistance to natural or man-made wear and tear.

2.2.1 Structural defects

Structural defects are related to the failure of the sub-grade or pavement layers. They might appear similar to some of the surface defects, but the cause is rooted in the lower strata of the road/pavement. More frequently than not, structural problems are related to material, pavement depth, geometry or drainage deficiencies. Structural defects typically appear as soft or wet patches, larger depressions or loss of pavement. Structural defects may in some cases become so serious that it may impact on accessibility of the road.

2.2.2 Surface defects

Road Roughness is a function of some defects listed below (e.g. potholes, corrugations and stoniness). Although a derived property, (secondary defect), roughness is an important factor to consider for the selection of surfacing options. Road user cost and user satisfaction is a direct function of roughness, hence its use in all economic justifications for road upgrades. It is also used in determining the maintenance frequencies of unsealed roads. For example, some management systems predict the optimal blading cycle for unsealed roads based on roughness levels (See Section 2.4).

Corrugations are the result of material displacement under the moving vehicle tyre due to the loose surface material and vehicle dynamics. Regular ridges are formed across the road surface. Under the corrugation the road base is sound. The regular short wave-length deformation is clearly noticeable and can severely affect safety, comfort and speed. Surfaces with low plasticity and high degree of loss of fine aggregate are particularly susceptible to forming corrugations. The rate of corrugation development is a function of material and traffic; e.g. for a traffic of 100 vpd corrugations may develop within 7 days for weaker type soils. (OECD 1987)

Considering the cause of corrugation, regular grading or dragging operation may address only the symptom rather then the cause. Long-term solutions can only be expected by applying a more suitable wearing course material by producing a tight bound surface.

Potholes appear as localised defects, growing in depth and diameter with the traffic. Potholes develop most frequently where the drainage is less functional, or cross-fall is inadequate. Typically, these locations include flat grades and slopes, bridge approaches, super elevation changes, etc. Patching is the common cure, but long-term remedy includes resolving drainage deficiencies and in particular restoration of cross-fall to 4-6%.

Rutting is a longitudinal deformation formed in the wheel paths. Dry season rutting is related to the use of non-cohesive materials with low fines content, such as some gravels and sands. Wet season rutting is found in materials sensitive to water. Rutting is sometimes categorised as structural failure, as the deformation may take place in the base or subgrade layers. However, this deformation is due to water ingress, i.e. lack of adequate drainage. Rutting can be largely prevented by using appropriate materials (with appropriate grading), applying a tightly bound wearing course and ensuring adequate surface drainage. (Applying or restoring cross-fall is a commonly used and effective method).

Scouring/erosion is the loss of surface material caused by free flowing water on the road and vehicular traffic. Erosion of the surface material can be prevented by;

- Increasing the shear strength of the surface material by using well graded, cohesive material;
- Retarding the rate of water flow on the road surface; and,
- Avoiding the use of unsealed surfaces on steep grades.

Earth and gravel surfaces usually suffer from excessive erosion with longitudinal gradients of more than 6% in modest rainfall locations. In areas with rainfall of more than 500 mm/year erosion may be excessive on gradient above 4%.

Ravelling or loose surface material creates a safety hazard for the unaware, as the surface seems to be firm, but has a very low friction due to the loose aggregate. Loss of surface material fines aggravates the situation, which can be remedied effectively by restoring the density of the surface. This may involve the replenishment of fines by bringing in new material, providing moisture or ensuring cohesiveness by other methods.

Loss of surface material is particularly critical for gravel roads, where the loss or replacement of the lost gravel represents substantial costs. Rates of loss depend on material quality, traffic, rainfall, gradient and maintenance regime. For example, rates of loss can typically be 2 to 5 cm per year in a medium to high rainfall tropical environment (Intech-TRL, 2005). Replacement of gravel can be as much as 60% of the total maintenance costs (ARRB 2000). Compaction of the surface and the use of appropriate grading techniques can reduce surface loss.

Dustiness is a safety, health and environmental concern. Dust generated by the traffic causes respiratory ailments and damage to property, possessions, vehicles and machinery. Discomfort and cleanliness problems are experienced by road users and residence along the route. Dust can also harm the environment and can reduce productivity on the affected agricultural area. Reduced visibility may lead to accidents. Loss of fines can also rapidly deteriorate the cohesiveness of the surface material.

Stoniness (fixed or loose) is a safety hazard in both dry and wet weather. Loose aggregate prevents tire adhesion to the road surface and impairs braking and cornering.

Slippery surface of an unsealed road is a significant safety problem. In wet weather, excessive fines or plastic material on the surface creates a slippery, low friction surface.

The lack of adequate cross fall contributes to slipperiness, as it extends the presence of water on the surface. Once a surface becomes slippery, it will need restoration, which may include re-gravelling, re-shaping of the cross-section to a crown with 4-6% cross-fall or removal and replacement of affected areas.

2.3 Maintaining unsealed roads

This section deals principally with the maintenance activities that affect the performance of the road surface. It does not include maintenance of drainage structures and bridges which is beyond the scope of this document.

The broad objective of maintenance activities on unsealed roads is to preserve the road in a condition close to its intended or as-constructed state, to ensure an acceptable level of service through control of the various deterioration modes such as gravel loss, dust poor ride quality.

2.3.1 Material Quality

Material selection is one of the most crucial design and maintenance considerations that affect the performance of unsealed roads. Often, alternative surfacing options are considered for poor performing unsealed roads, whilst the problem can be resolved by using quality materials. In this context material quality also includes - beside the material type - other characteristics such as grading. Research completed by both the CSIR and ARRB have indicated that by ensuring appropriate grading distribution will greatly enhance the performance of unsealed roads (Paige-Green, 1989 and ARRB, 2000). As a result, in-situ crushing equipment yielded excellent results.

The availability of quality material obviously influences the economical considerations of the surfacing options and is therefore one of the inputs to the decision framework proposed in this report (See Figure 5.3).

2.3.2 Drainage

In most climates (except arid), the most important maintenance function is to keep the drainage system operational as a routine activity to minimise deterioration of the road surface/structure. Drainage consists of:

- Surface crossfall
- Side drains
- Mitre or turn out drains
- Relief drains
- Cut-off/interceptor drains
- Culverts, drifts and structures

Crossfall is normally dealt with under grading/reshaping (See Section 2.3.4). The other components of the drainage system need to be regularly cleaned of silt, material accumulations and debris that may cause it to cease to function properly. These activities can be carried out by labour, although in some situations motorgraders or towed graders may be used for side and mitre/turn out drains. Erosion control measures such as scour checks require maintenance and any erosion damage should be repaired.

2.3.3 Vegetation

In most climates (except arid), the control of grass, shrubs, bushes and trees is a routine maintenance requirement. This control relates to the road margins to ensure safe visibility by road users, and the effective operation of the drainage system.

2.3.4 Grading/Reshaping

Unsealed roads require regular maintenance to ensure adequate ride quality and safety. This is usually achieved by routine and periodic grading or (also referred to as blading).

Routine or regular grading, or as frequently referred to as "smoothing grading", is performed relatively frequently to re-distribute surfacing material across the crown of the road. Cut depths are typically up to 5cm. Smoothing operations help to maintain the crown profile and necessary cross-fall, thus ensuring adequate surface drainage. The grader blade is typically set at an angle (10-15 degrees) to minimise cut depth and to get a dragging action. Routine grading frequency should typically be between 1 and 6 times per year, depending on materials, traffic and weather. For simplicity of programming, the frequency selected should be an even divisor of 12 months (*i.e.* 1, 2, 3, 4, 6, *etc.*). Routine grading can be carried out by motorgraders. However, in low wage economies or remote rural areas, it can be achieved more cheaply using agricultural tractors (>35hp : 26kW) and towed graders (>1 tonne for earth roads and >2 tonnes for gravel) (Gongera 2003). Reshaping can also be carried out using labour and hand tools, achieving good results if the appropriate tools and templates are used (level pegs, string-lines and camber boards) (MOW Tanzania 1997).

The cleaning of side and turn out drains is sometimes part of the regular routine grading operations. However for gravel roads this risks contamination of the surface with unsuitable soil from the drains.

Periodic operations usually involve medium to heavy grading. These are carried out to re-instate the cross-section of the road. Reshaping of the crown is usually necessary when it is heavily deformed due to environmental or traffic conditions. Heavy grading is required to remove deep corrugations and other smaller defects. For major or extensive defects, ripping, reworking watering and compaction may be necessary. Periodic grading is often required when routine grading has not been possible for some time due to funding or resource constraints. Heavy Grading usually requires a motorgrader of at least 100hp (75kW), or a 100hp 4WD agricultural tractor and heavy (> 4 tonnes) towed grader. Alternatively labour can carry out the same operation, as described for routine reshaping.

The benefits of grading operations are usually measured with the reduced roughness and speed of travel, which, in turn are directly related to vehicle operating costs. The desirable roughness is a matter of policy that is set according to the mixture of vehicles using the given road and the resources likely to be available. The frequency of grading is ideally determined by the time the road develops unacceptable level of roughness. In lieu of roughness measurement, regular or scheduled grading is commonly used.

Regular grading has a disadvantage of loosening up the wearing coarse of the unsealed road and as a result may increase the rate of material loss. Good grading practises such as grading during times when the wearing coarse has higher moisture content is advisable. Routine Grading in the dry season can be of limited effectiveness as the absence of moisture can prevent the reshaped material from 'bedding down' (unless watered at additional cost). More damage can be caused by dry grading than not doing the grading at all (ARRB 2000).

Dry season redistribution of loose surface material and removal of minor corrugations can be achieved by regular dragging (Gongera 2003). Drags can be pulled by agricultural tractors or other vehicles and be simply fabricated at very low cost from old grader blades or tyres.

2.3.5 Ripping and Reworking Existing Layers

Ripping and reworking of existing layers may also be considered as a severe case of grading. The operation entails scarifying the surface and adding and mixing new materials. Scarifying is usually done to the depth of the defect (i.e. potholes). Typically, the blade (mouldboard) is tilted to about 30-45 degrees to allow rolling the lose material. Adequate material moisture content and presence of fines is essential for successful reworking of the pavement.

Ripping and reworking may also be conducted with rotomill or other equipment designed to mill and reshape the surface. This type of equipment is usually more expensive and requires specific skills. As opposed to graders, rotomills and other purpose built machinery cannot be used for other purposes (like graders), so their use on very low volume roads is usually not warranted.

2.3.6 Re-Gravelling

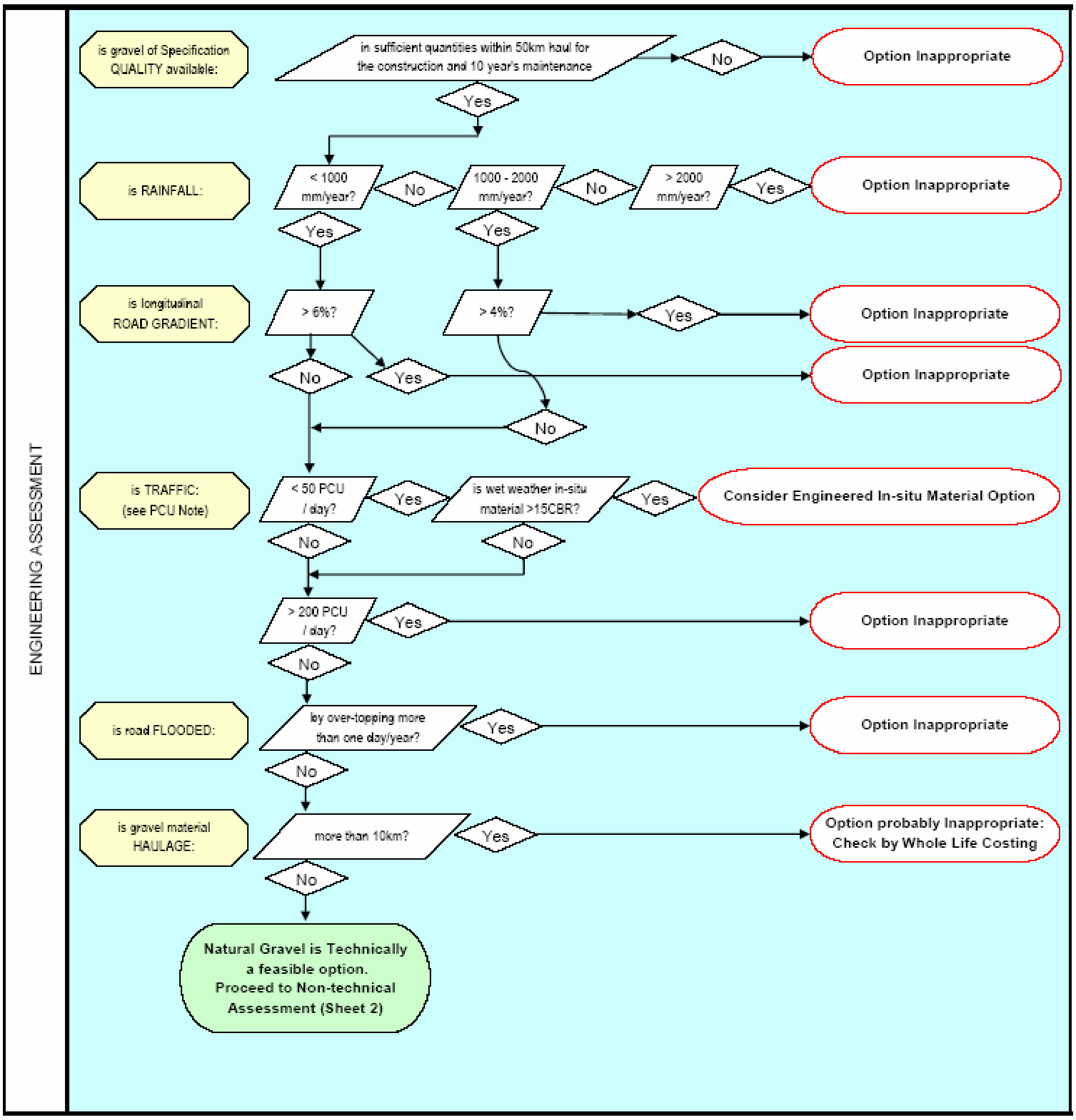
Re-graveling replenishes the lost gravel and restores both the service level and the load bearing capacity of the road. This is the principal periodic maintenance operation for gravel roads. However, re-gravelling has serious disadvantages, due to simple fact, that gravel is a "wasting" surface that is consumed or lost during the life of the pavement. Consequently, if possible under given circumstances gravel should not be used under the following circumstances: (Petts, et al, 2004)

- Gravel quality is poor;
- Compaction and thickness cannot be ensured;
- Haul distances are long;
- Rainfall is very high;[1]
- There are dry season dust problems;
- High traffic levels;
- Steep longitudinal gradients;
- Adequate maintenance cannot be provided;
- Subgrade is weak or soaked (high risk of flooding); and,

[1] Note: Although high rainfall is often used as motivation to seal a road, it should be kept in mind that paved roads also perform poorer under wet conditions. However, it is generally accepted that paved roads are built to higher geometrical and material standards and provide reliable access in wet conditions. Obviously, the performance of unsealed roads could also be enhanced by adopting higher geometrical, drainage and material standards.

- Gravel deposits are limited or environmentally sensitive;

According to the experience gained during the Vietnam study, a flowchart was developed to assess the appropriateness of natural gravel as a rural road surface option (see Figure 2.1).



NOTES: PCU = Passenger Car Unit (other vehicle types to be converted from traffic surveys and maximum predicted daily flows for next 3 years).
CBR = California Bearing Ratio - Strength in situ measured by DCP, or to be decided by visual assessment
DCP = Dynamic Cone Penetrometer
Engineered Insitu Material = Earth Road Standard with maintained camber and effective drainage system

Figure 2.1: Decision Flow Chart for the Consideration of Natural Gravel as a Rural Road Surface Option (Petts. et.al, 2005)

There are several models available to predict gravel loss. The most frequently used factors in these models are: (Jones 1999, ARRB 2000)

- Degradation of stone;
- Climatic conditions;

- Scouring and erosion;
- Traffic; and,
- Maintenance practice.

Recent investigations of gravel performance in a range of tropical medium to high rainfall conditions are reported by Petts. et.al (2005). A distribution of the gravel loss observed across the experiment is depicted in Figure 2.2.

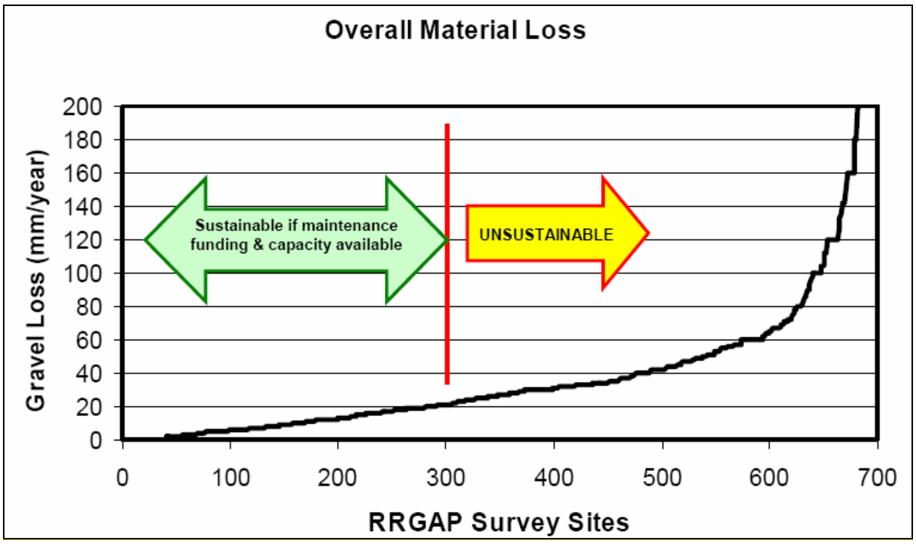


Figure 2.2: Material Loss Summary of the Vietnam Experiment (Petts. et. al, 2005)

Notes: Median rainfall = 26mm/yr, percentage rainfall greater than 40mm = 29%

The figure clearly illustrates that there are some sections that have an unacceptable rate of gravel loss. Alternative surfacing material must be considered on these sections.

2.4 Unsealed Roads Management Systems

Management systems may be used to support the decision process for upgrading unsealed roads to sealed roads. Although management systems are widely adopted in developing and emerging countries, especially for paved networks, the adoption of unsealed roads management systems varies significantly in function and sophistication. These factors are discussed further in the following sections.

2.4.1 Functionality

The functionality of a management system is determined by a number of factors that include:

- Network size and characteristic;
- Availability of technology and resources;
- Level of understanding; and,
- Complexity of the management/business process.

Ultimately, the functionality of the Unsealed Road Management System depends on the purpose for which it is used. For example, if it is used to manage maintenance scheduling aimed at maximising the service to the public, then it could consist of either a predicted performance based system and/or a public complaint system. Some systems may be aimed at operational level activity planning, while others may be aimed at a long-term prediction of maintenance needs. Henderson and Van Zyl (2004) describe the functionality and components of an operation oriented system. Figure 2.3 illustrates a typical process for a system capable of prediction of long-term maintenance needs. It should be noted that these types of systems are aimed at network level management of maintenance needs. Therefore a typical output from this system could include the upgrading needs on the network to go from unsealed to paved roads. The figure shows the basic components of the system being data, system design, analysis process and execution/operation.

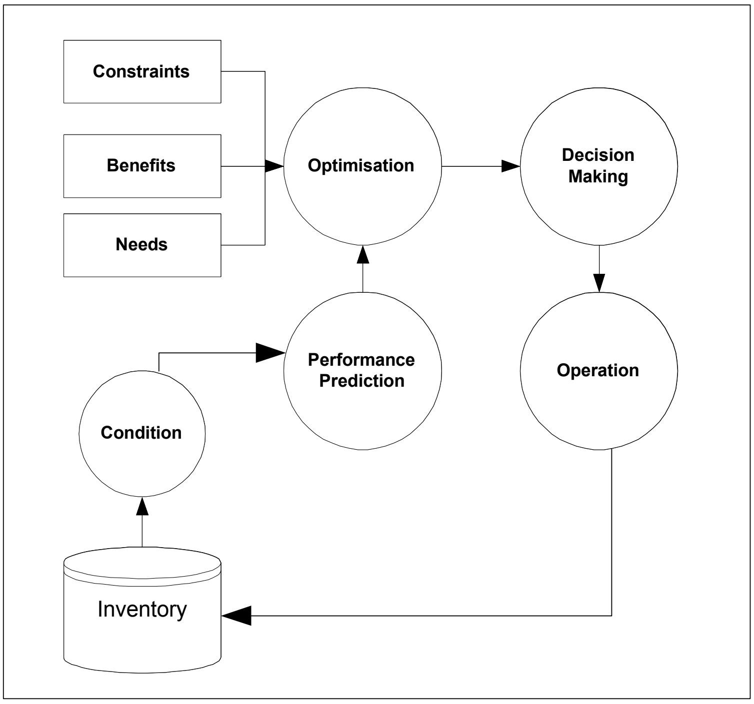


Figure 2.3: Schematic Presentation of an Unsealed Management System (Henning, 2003)

There are a number of systems that have either added functionality within or integration with other systems thus enhancing the overall functionality of the unsealed road system. Components that may form part of the Road Management System (sealed and unsealed) include:

- Database - referencing, inventory, condition, maintenance history and cost;
- Analysis Capability – prioritisation, optimisation and/or performance prediction;
- Geographical Information System (GIS) – map display of unsealed roads use or condition;
- Operational Management – task scheduling and planning;
- Safety – crashes, signs and hazard registry;
- Plant Management – graders, staff, maintenance; and,
- Public Complaints – call centre logs, performance, contractor details.

Experience has indicated that systems are very useful in the management of large or complex networks. An effective Unsealed Road Management System should also assist in determining the most appropriate surfacing alternatives. The full description of management system functionality falls beyond the scope of this document.

2.4.2 System Sophistication

Selecting the appropriate level of sophistication of management systems is normally a challenge for the development teams. In most cases the development of unsealed road management systems was an evolutionary process. Because of this incremental development, unsealed management systems are in most cases found to be fit for purpose. This confirms the statement by Levy (1984):

> *"A complex system that works is invariably found to have evolved from a simple system that worked. A complex system designed from scratch never works and cannot be made to work. You have to start over, beginning with a working simple system."*

The sophistication and complexity of the system may be reflected in the following:

- data entry and access. For example the system developed for the Western Cape is accessible through the internet (Henderson and Van Zyl, 2004);
- data quantity it can hold and how this data is integrated with other systems;
- analyses it can perform; and,
- outputs produced and how these outputs are integrated with the business systems or other management systems such as GIS.

The complexity and sophistication of a system will contribute to defining the network's maintenance and other needs. For example, if gravel loss models are incorporated into an unsealed management system, it will be able to predict future re-graveling needs. In a strategic review of unsealed road management system requirements HTC (2003) defined some expected outputs from a system capable of long-term prediction.

"Some of the questions that modelling may be able to answer include:

- *Will the initial higher cost of providing mechanical compaction after grading and regravelling be justified by decreased material loss and improved pavement performance?*
- *Is it worth increasing the clay content of local coarse gravels to improve their performance?*
- *What is the optimal material depth (in terms of economics) in a pavement for a given traffic loading? i.e. at what point are the maintenance requirements no longer significantly reduced by adding extra gravel?*
- *What benefits can be gained by taking measures to actively reduce dust across the network?*
- *What are the cost implications?*
- *What portion of the budget can be applied to other types of work, such as signage, emergency work, drainage, safety improvements?"*

If the Unsealed Road Management System is required to analyse the alternative surfacing options, it will need to include some – but preferably all - of the following components:

- Gravel loss and roughness prediction models;
- Routine and periodic maintenance resources and cost models;
- Vehicle operating costs models;
- Dust generation and consequences;
- Performance characteristics of all surfacing options;
- Socio-economic models for employment and local resource use of the various surfacing and technology options (Potential poverty reduction impact);
- Risk assessment of non- or delayed maintenance;
- All the data items as required by each of the above.

Jones et al (2001) describe how the above mentioned components were used for the evaluation of dust palliatives in an Unsealed Management System. More detail on the gravel loss models is provided in Chapter 3.

As with all decision management systems, they will only be as good as the quality of the relationships and data input. There is probably insufficient appreciation of the range of factors that influence costs of construction, and particularly maintenance. Factors that can affect costs by whole number multiples are:

- implementation method;
- technology;
- scale of works;
- logistics;
- motivation and skills of personnel;
- wage rates;
- operational environment;
- payment arrangements;
- overheads; and,
- cost of finance.

It is therefore risky to transfer costs from country to country, and even within some countries. Such cost figures should only be used as broad indicative guidelines. There is no substitute for carefully collected local productivity and cost data.

3. Case Studies

3.1 Long-term Performance Trials

3.1.1 Purpose

Long-term performance studies on unsealed roads are undertaken in order to understand and quantify the behaviour of pavements under their operational conditions, including climate and traffic loading. The specifics of each performance study will vary but will in general have the following objectives in common:

- To establish deterioration models for local roads in Australia Giummarra, (2004) recommended the monitoring of:
  - Road roughness;
  - Gravel loss;
  - Loss of shape; and,
  - Loose stones.
- To monitor the deterioration of the unsealed road as a function of variables such as (based on MWH, 2001):
  - Maintenance practice;
  - Site geometry;
  - Climate and rainfall;
  - Traffic volume and types; and,
  - Aggregate properties.
- Ensure regular condition surveys are undertaken to monitor change in parameters such as (based on Paige-Green, 1989):
  - Gravel loss;
  - In-situ testing;
  - Roughness;
  - Rut depth
  - Corrugation;
  - Visual assessments;
- It must consist of a number of sections that are determined according to an experimental design matrix. The design matrix is developed to take account of a range of factors that the researcher wants to include in the experiment.

On completion of the performance study, deterioration expressions or models are developed and adopted into a management system as indicated in Figure 2.3. The models can be used to predict the deterioration of the unsealed roads given certain levels of funding or maintenance efforts. This allows the model to be used for the economic analysis of different maintenance regimes and wearing course material. If combined with models for different surfacing options, it could be used for an economic analysis, investigating different surfacing scenarios.

3.1.2 Some Examples of Unsealed Road Studies

The full description of unsealed road performance studies falls outside the scope of this report. However, it is important to be aware of some the studies since it could be a useful input into future studies for surfacing alternatives. Table 3.1 lists three identified as examples.

Other studies include studies undertaken by TRRL in Kenya, Botswana, Thailand and Zimbabwe. Morosiuk and Toole (1997) compared these studies in the report "*Review of research on the deterioration of unpaved road*s".

Surfacing trials which are directly related to this report include road trials in Vietnam, under the auspices of the Ministry of Transport, with the support of DFID and World Bank. (Intech Associates 2003) Details on the study and a summary of the results are presented in Section 3.2.

Table 3.1: A Summary of Some Long-term Performance Studies for Unsealed Roads

			Study Details				
Researcher	**Country**	**Study Main Objectives**	**Design Matrix**	**Traffic Range**	**Climate/Rainfall**	**Material**	**Outcomes/Status**
			The original study consisted of 48 sections. Design matrix Factors: surface material, traffic, vertical and horizontal alignment.	11 to 288 passenger car and 1 to 435 two axle trucks per day	Rainfall - 1200 to 2000 mm/year Climate being classified between moist sub-humid to humid.	Laterite and Quartzite Some earth roads (without wearing course) were also monitored.	Unsealed road deterioration models adopted in HDM-III and HDM-4 including: • Roughness; • Material loss; • Passibility; and, • Rutting (not adopted in HDM)
Paige-Green (1989)	South Africa & Namibia	To develop performance-related specifications for gravel wearing courses. To develop unsealed road deterioration relationship for Southern Africa	A total of 110 sections Design matrix Factors: Surface material, traffic, Weinert N-value	Total Traffic between 18 to 608 per day	Rainfall – 300-1100mm/yr Dry arid to moist humid	Acid and basic crystalline, high silica, arenaceous, argillaceous, pedocretes	Performance related specification. Unsealed road deterioration models including: • Roughness; • Material loss
Jones (1998)	South Africa	Calibrate unsealed road models for Gauteng Province	36 sections	Total Traffic 45 - >300	Rainfall 500-700	Acid and basic crystalline, high silica, arenaceous, argillaceous, pedocretes.	SA unsealed models most appropriate for Gauteng
Jones	Southern	Determine whether	30 sections	Total Traffic	Rainfall – 300-	Acid and basic	• Developed

			Study Details				
Researcher	**Country**	**Study Main Objectives**	**Design Matrix**	**Traffic Range**	**Climate/Rainfall**	**Material**	**Outcomes/Status**
(1999)	Africa	dust suppressants are providing cost-effective maintenance options	(including mine haul roads)	45 - >300	1100mm/yr Dry arid to moist humid	crystalline, high silica, arenaceous, argillaceous, pedocretes	multiplication factors for SA unsealed road models (roughness and material loss) for dust palliative treatments as well as a dust prediction model
Giummarra (2001)	Australia - Tasmania	To evaluate the performance of four different running surfaces as a function of maintaining the hard crust, minimising wear, ravelling and dust.	A single road of 2.7 km was divided into 300m test sections in order to trial different treatment options.	A single traffic volume was used for the full experiment – ADT = 83	Temperate climate 1400 – 1600 mm/year	Treatment A - applying current practices and served as the control section Treatment B – existing material with added clay Treatment C – existing material with an overlay specially mixed wearing course (gravel clay mix) Treatment D - existing material with an overlay of specially mixed wearing course (oily shale material)	Demonstrated the different performance outcomes from each surface material in relation to • Roughness • Dust emissions • Ravelling • Gravel loss • Loss of shape In addition a cost effectiveness comparison was performed on each alternative

3.2 Pavement and Surfacing Trials- Vietnam

The Vietnam field trials involve the testing of 16 different pavement designs and compositions of alternative pavements at four different regions (Petts. et al, 2005). All pavements are constructed to well-defined specifications and are monitored according to a schedule.

The objective of the research programme is to enable experience to be gained with a range of alternative road surfaces that better use local resources in a sustainable way, minimising whole-life-costs and supporting the government's poverty alleviation and road maintenance policies. The ultimate objective of the project is to complement the national standards with a full range of surfacing options.

The initial investigation identified four regions with different characteristics, namely

- Mekong Delta;
- Central Coastal;
- Northern Mountains; and,
- Central Highlands.

During the preparatory phase of the trial the overseeing committee structure and participants were identified, the available pre-trial information was summarised and the trial details were planned.

Phase I investigations identified the following principal considerations in selecting rural road options:

- Reduced maintenance burden, compared to the traditional gravel surfacing;
- Reduced initial construction cost;
- Low expected whole of life cost;
- Improved sustainability;
- Resistance to flood damage;
- Adequate load spreading capabilities;
- Durability under the expected traffic, weather and other environmental conditions;
- Low capital investment requirements for the construction;
- Use of local labour and skills to create employment opportunities;
- Socially and environmentally acceptable methods and materials; and,
- Techniques suitable for local communities to easily adapt for other developmental purposes using local resources.

Based on the above criteria, the following pavement types were selected for the trial:

- Dressed stone – local skills in stone cutting have been long established, so despite the high labour intensity of the technology, it was deemed economical, mainly due to its durability and impact on poverty reduction;
- Bamboo reinforced concrete has been found a successful and environmentally favourable alternative to steel reinforcement;

- Steel reinforced concrete was used as a reference or benchmark for comparison with bamboo reinforced concrete;
- Concrete bricks were selected due to their good load spreading capability and reusability;
- Bitumen-emulsion seals are used on waterbound or dry bound macadam or stabilised soil. These bituminous surfaces represent a labour-friendly and good protection of the surface; and,
- Fired Clay Brick paving is a traditional paving material in Vietnam, produced locally using coal or wood fuel. The interesting development in these project trials is the firing using rice husk, an agricultural waste product, in small scale kilns. Quality is comparable with factory coal fired bricks. The high local labour/enterprise content means that most costs are recycled in the community.

The trial sections incorporate 100 – 200m long sections of the selected paving materials. Typically, each trial site includes about 10-13 trial sections with different materials or designs. The sites also include control sections to benchmark the performance.

The monitoring includes the pre-construction, construction and post-construction conditions and circumstances. Data is collected on the following aspects:

- Road environment factors;
- Construction costs;
- Construction procedures;
- Maintenance costs;
- Traffic;
- Pavement performance/deterioration; and,
- Socio-environmental issues.

The condition testing programme includes visual condition assessment, roughness, deformation, deflection, strength, moisture content, density and trial pitting and sampling Road maintenance during the trial must comply with agreed procedures and methodology.

Based on this study the Rural Road Surfacing Guidelines were developed as illustrated in Figure 3.1.

Apart from assessing gravel performance the study has raised other important issues, such as (Imtech, 2005):

1. *"The investigations have indicated the effectiveness of unsealed stone macadam in providing a sustainable surface/road-base, albeit with high surface erosion or roughness penalties. It is suggested that this option would be ideally suited to a staged construction approach, with an appropriate sealing option following-on at a later date from the initial construction.*
2. *Other techniques utilising natural stone, without bitumen or cement binder, could have superior performance to gravel, but with reasonable initial costs and lower maintenance liabilities. These surface options include hand packed stone and cobble stone paving.*

3. *Staged construction using gravel as the initial construction material has the disadvantage that significant degradation may occur on the surface unless the seal is applied within 6 months, or at least before the first rainy season.*
4. *Composite construction should be considered as a strategy in future rural road programmes. This involves the construction of different surfacing options along a road link in response to differing environment impacts. In appropriate cases this could involve employing an engineered natural surface option. "*

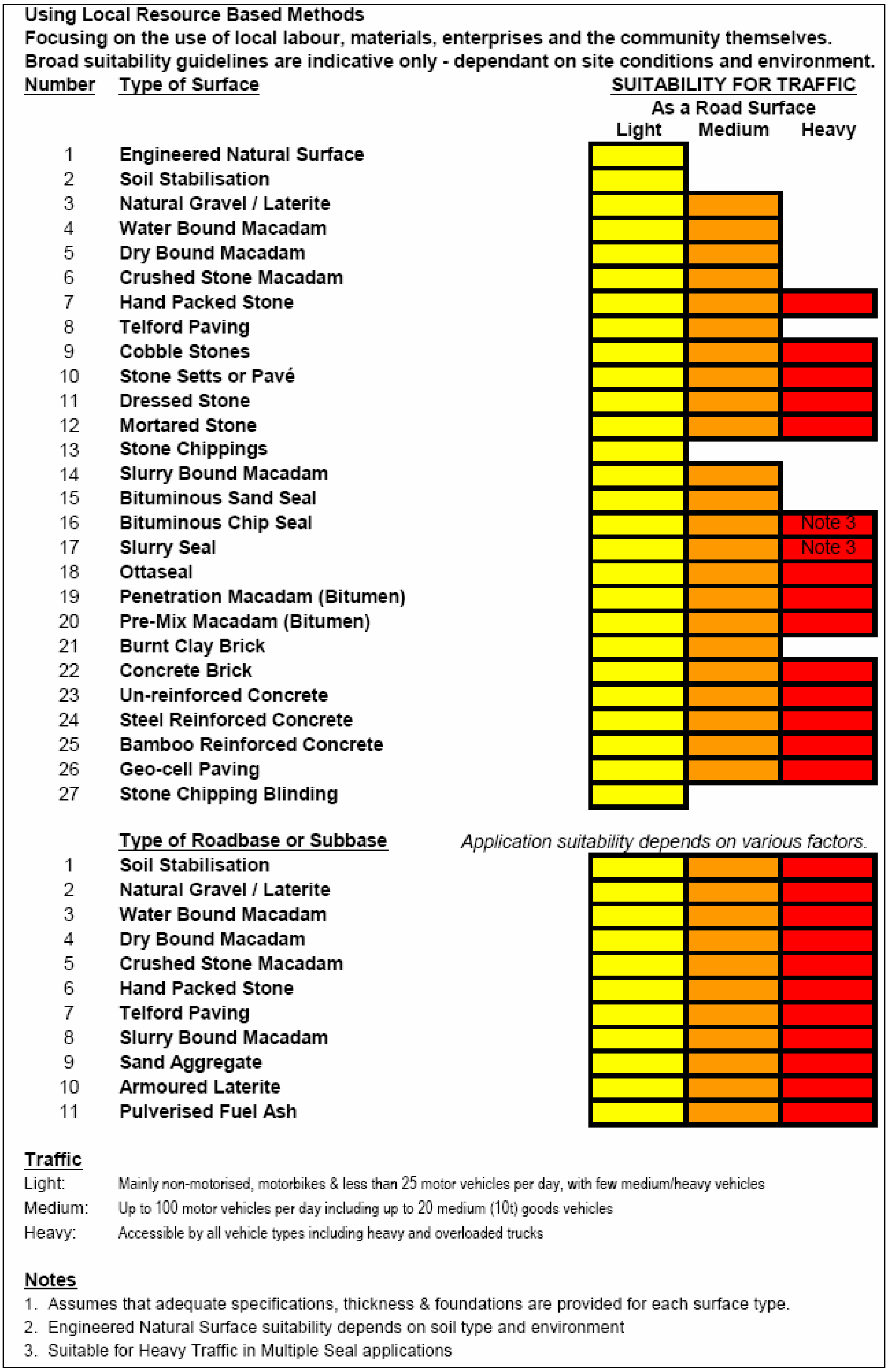


Figure 3.1: Rural Road Surfacing Guidelines as Developed in Vietnam (Petts. et. al, 2005)

Part 2 – Decision Framework: Surfacing Alternatives for Unsealed Rural Roads

4. International Practice: Surfacing Decision Making

4.1 Surfacing Options

Pavement technology and thus surfacing options, have evolved over a long period. New materials and technologies keep emerging. The current chapter provides a broad overview of key methods, without attempting to include all variations of the construction technology. The purpose of this chapter is to assist in selecting surfacing types, without removing the need for engineering design. For example, dust suppressants are considered as one group, leaving the selection of the right dust suppressant to the reader.

Surfaces may be grouped according to many aspects; here they are grouped according to their dominating constituent. A further subdivision is offered according to the processing or use of the surfacing materials. The classification is summarised to:

4.1.1 Natural surfacing

Natural surfaces are typical for the unsealed, formed roads; sometimes categorised as 'engineered earth roads' or 'engineered natural surfaces'. Upgrading these roads normally involves more than just changing the surface since it would not be sufficient in terms of geometry and drainage.

4.1.2 Gravel

Gravel surfaces include typically 150-250mm thick natural gravel or other imported layer that is worn down by traffic and the environment. Gravel roads may be left untreated or can be treated with a specially blended wearing course, dust suppressants or stabilisation agents.

4.1.3 Dust Suppressants

Dust control has major environmental, health safety and economic importance. Dust is caused by the loss of fine particles from the road surfacing due to traffic and environmental impact. The loss of fines increases the permeability of the surface and reduces the cohesion of the surfacing material at the same time. Reducing loss of fines increases the life of the surfacing, thus reduces maintenance demand.

Controlling dust will improve safety and comfort of the road users, reduce damage to the environment and improve socio economic conditions. Reduced or no dust will allow higher speeds, thus improved transport efficiency. Dust is also a particular concern for certain farming areas. For example, dust can negatively effect the production of crop types such as cotton and tobacco (Henning and Bezuidenhout, 1991).

Dust control techniques fall into the following categories: (Foley 1996)

- Good construction practice;
- Mechanical stabilisation; and,
- Chemical dust suppressants in addition to the above.

According to Foley (1996), most chemical dust suppressants are short term, bridging solutions and short of sealing the road there are no known ways to eliminate dust emissions efficiently. One particular problem is that most of the chemical additive suppliers have entered the market without recognised research. The behaviour and performance of these additives are, in most cases, poorly understood which has lead to the application of some additives in the wrong locations or under the wrong environment. According to Jones and Ventura (2003), these products are material and/or climate dependant and the associated life-cycle cost may vary significantly. It is therefore important to investigate the performance under controlled experiments in order to understand the limitations and true life-cycle cost considerations.

There are some products that have been subjected to controlled tests such as been undertaken in Southern Africa (Jones, 1999) and have performed well under the conditions they were designed for. Table 4.1 list some of the generic additive products with associated application potential.

Table 4.1: Summary of Chemical Additives and Performance Enhancing Chemicals

Category	Effect on Unsealed Material	Application
	Dust Palliatives	
Wetting agents (Surfactants)	Surfactants reduce surface tension so moisture can wet particles. Due to the increased moisture, the binding with the soil improves. Natural water, detergents or soaps are typical wetting agents.	The action of surfactants is typically short term and they need to be applied regularly, even daily. Their use is limited and needs to be justified by special circumstances. Some applications may include – mine haul roads and construction sites.
Salts/Chlorides	Chlorides reduce the repulsive forces between soil particles by increasing moisture content. Chlorides typically draw moisture from the air due to their hydroscopic and deliquescent properties.	As the source of the moisture is the air, the underlying requirement for the effective working of these treatments is a relatively humid climate. None of the chlorides work in arid areas. Typically, calcium and magnesium require at least 30-40% humidity, whilst sodium ceases to be effective below 70% humidity (ARRB 2000). Consequently, sodium is used less frequently and it is less effective.
Natural Polymers	They are based on lingosulfonate which is a by-product of the pulp milling industry. They act as a clay-dispersant, making the clay more plastic at low,- moisture content.	Polymers physically bind particles of the road material together. These products are highly soluble in water thus requiring re-application and could be an effective interim before a permanent surface is provided. Application areas include mine

Category	Effect on Unsealed Material	Application
		and forest haul roads. These products can be sprayed or mixed in during construction.
Modified Waxes	Waxes are manufactured by the petrochemical industry. They act as a soil binder and can expel absorbed water from the soil and by doing so, the air voids decrease and compaction increases.	The performance is a function of road and ambient temperature. Above 35 ˚C, the wax softens and penetrates the road. Could be used in conjunction with calcium chloride and lignosulfonate to improve performance in wet weather
Petroleum Resins	They usually are a blend of natural polymers and petroleum based additives. Some research has been conducted in the USA.	Has the potential as dust palliatives and stabilisers but cost is relatively high.
Bitumen and Tar	Bitumen additives are often a by-product of the petrochemical and bitumen supplier's product line. Tar based applications is a by-product from the coal industry or synthetic fuel distillates.	Products are sprayed onto the road and in some cases blended with sand, which performs similarly to a sand seal, which can last for up to three years. Tar can perform similar to the bitumen products but some countries ban the use of tar products due to environmental and health concerns.
Compaction Aids and Stabilisers		
Synthetic Polymer Emulsions	Polymer dispersions are suspensions of synthetic polymers. Many formulations have been developed as soil "conditioning" applications, which are potentially applicable for dust control and stabilisation of unsealed roads.	Most documented research was originating from the agricultural industry. Limited research was done in road applications.
Bitumen and Tar	See above	
Sulfonated Oils	Consist of strongly acidic sulphur based organic mineral oils. These products were developed in the USA during the 60's.	The stabilisation process is complex and material dependant. They have the ability to displace and replace exchange cations in clay and waterproof clay. It may also improve the soaked strength of high plasticity soils.
Enzymes and Biological Agents	Most of these product types will reduce the surface tension of water, thereby acting as a compaction aid. Some enzymes may result in a bond between particles due to crystallisation.	Little publications exist on the application of these material types.

Note: Based on Foley (1996) and Jones and Ventura (2003)

Typically, dust palliatives are used for traffic volumes up to 250 vpd (for developing countries) – beyond this traffic volume seal surfacing should be considered as an economical alternative. Furthermore, research in Southern Africa (SATCC 2003) suggests that sealing can be justified at much lower traffic (<100 vpd) in some circumstances.

Some of the dust control methods are also called "stabilisation" as they increase surface cohesion.

Mechanical stabilisation is the blending of various fractions of stones, sand and fines to achieve the required grading to gain maximum density and strength. A wearing course for unsealed roads is a special blend of well graded aggregate with high plasticity (PI). This can produce a well bound and tight surface that better resists wheel abrasion from traffic and repel water ingress. Having a high PI as the base will lead to the pavement being more vulnerable to moisture ingress.

When selecting dust palliatives, the climate, the predominant wearing course or road surface material and the availability of the preferred material needs to be considered. An example of a decision assisting chart is shown in Figure 4.1.

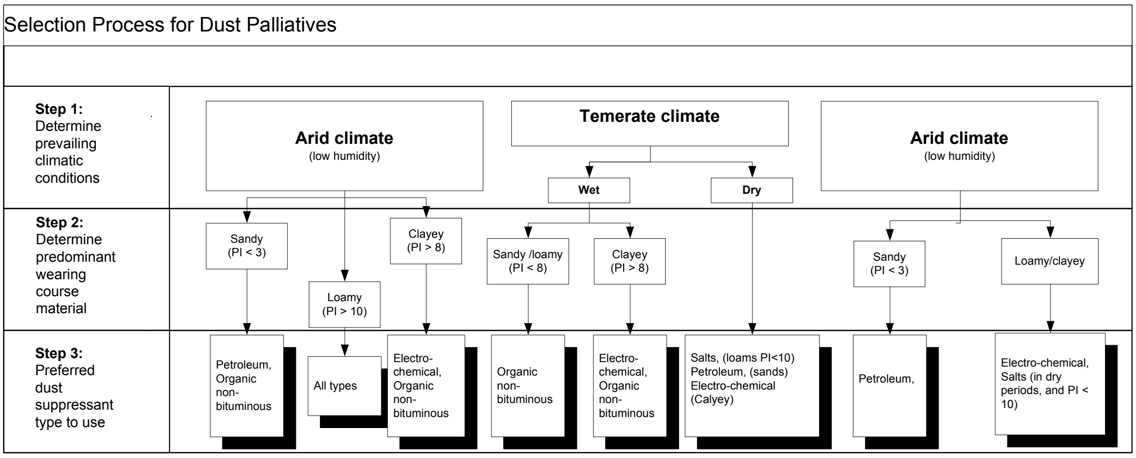


Figure 4.1: Decision Chart for Choosing the Appropriate Dust Palliative (based on Foley et al 1996)

All palliatives must be used according to manufactures recommendations. Some of them tend to leach out in heavy rain, causing environmental damage and creating a safety hazard by making the road and contaminated areas slippery.

4.1.4 Stone

Stone can be used in a number of ways to pave a road. Stone can be crushed to a small or to a large size, depending on the intended usage. Single sized or graded crushed stone pavements can be laid manually or with appropriate equipment. Crushed stone layers placed by machine usually require heavy equipment for compaction. Manually placed rock pavements may be prepared without heavy compaction equipment.

Stone may be cut (dressed) into blocks, and placed on a sand/gravel layer. Dressing and placement of the cut stone is a manual task requiring skills and experience.

4.1.5 Clay Brick

Paving blocks may be prepared from high quality clay bricks. This pavement type is very durable and has a very tight, smooth surface. Brick quality must be adequate and with suitable wet weather skid resistance. Bricks can be fired using coal, wood or waste products such as rice husk.

4.1.6 Concrete

Concrete pavements may be built with and without reinforcement. They are very durable, but mostly require substantial minimum thickness for high volume roads hence they are not cheap. The reinforcement may be steel or other appropriate material. Bamboo has been successfully used in some countries but its long term performance, especially under heavy traffic loading, is uncertain.

A special application of concrete is the concrete block pavement. Concrete block pavement is closer in its behaviour and performance to brick and clay bricks or dressed stone pavement, and uses less cement due to the reduced thicknesses possible with this technique.

4.1.7 Bituminous surfaces

There are a wide variety of bituminous surfaces that fall into two major groups. The bituminous surface could be either load bearing such as asphalt layers or just a thin water proofing seal.

Seals are essentially the combination of a bitumen film and stone embedded into it. Seals are flexible and easy to maintain surfaces but require imported (over long distances or into the country) processed material (bitumen) and good quality screened and crushed stone. However, sand seals and low grade natural aggregates have been successfully used (e.g. Cape and Otta seals) (SATCC 2003 and Øverby 1999) in appropriate circumstances. Bitumen may be penetration grades, cutback or (labour friendly) emulsion, depending on the application.

Bituminous mixes (asphalt layers) have significant thickness and may also have some load bearing capacity. The bitumen fills the voids between the crushed rock particles, thus providing a bonding layer between particles. Bituminous mixes may be classified according to many aspects, such as bitumen type, aggregate size or manufacturing method. For the purpose of this document, mixes are considered as plant mixes (hot or cold) or penetration mixes. These latter ones are prepared by laying the stone first and filling the voids with low viscosity bitumen.

4.1.8 Other

Other materials, such as recycled rubble, concrete or asphalt mix may be used to preserve and recycle materials. Though the material recycled may vary, the process typically involves crushing, screening and grading before stabilising and compacting the material. The use of recycling technology is more typical for locations with existing or even ageing infrastructure.

4.2 Surfacings and Alternative Treatments

The sealing of unsealed roads is a qualitative jump in terms of road construction and usually maintenance, although for some surfaces maintenance can be substantially reduced. Sealing an unsealed road provides benefits, such as (Transfund 2002):

- Productive gains on adjoining agricultural properties;
- Ameliorating driver and passenger discomfort (improving ride quality);
- Reducing the adverse effects on adjoining residential properties;
- Reduced vehicle operating costs; and,
- Travel time savings due to higher speed.

However, these benefits come at a significant cost, as the construction and maintenance costs are significantly different from those of unsealed roads. These will be discussed together later with the decision framework for upgrading or sealing the road.

Providing an all-weather surface usually requires:

- adequate geometric design standards;
- sufficient drainage; and,
- availability of technologies, materials and skills.

Table 4.2 summarises the alternative surfacing options for unpaved and unsealed roads.

Table 4.2:A Summary of Surfacing Options to Upgrade/Improve Unpaved or Unsealed Roads (based on Gourley et al, 2002)

No	Road Surface Improvement Options	Description
1	Slurry Bound Macadam Roadbase	A layer (about 7cm thick) of single size aggregate (typically 50mm) blinded[2] with smaller aggregate (typically 25mm), plate compacted and grouted with bitumen emulsion slurry before final compaction.
2	Bituminous Premix Macadam Surface	Graded crushed stone material (typically 28mm downwards) usually derived from fresh sound quarried rock, boulders or granular material and mixed with a bituminous binder (straight run, cutback or emulsion) and laid and compacted. Material may be hand or machine mixed and laid. Compaction by light or heavy equipment.
3	Penetration Macadam Surface	Two or three layers of single size crushed stone (of decreasing nominal aggregate size, e.g. 63 mm downwards) each compacted and with bitumen (straight run, cutback or emulsion) or road tar sprayed between each stone application.
4	Asphalt	hot or cold bituminous mix
5	Bituminous/Tar Sand Seal Surface	A seal consisting of a hand or machine applied film of bitumen (straight run, cutback or emulsion) or road tar followed by the application of excess angular sand or fine crushed stone, lightly rolled into the bitumen/tar.
6	Ottaseal Surface	A layer consisting of a hand or machine applied film of relatively soft bitumen (usually straight run or cutback) followed by the application of graded natural gravel or crushed stone aggregate (typically 16mm downwards), rolled into the bitumen using heavy pneumatic tyred rollers.
7	Bitumen/Tar Surface Dressing Surface	A seal consisting of a hand or machine applied film of bitumen (straight run, cutback or emulsion) or road tar followed by the application of a single layer of single sized (6 – 20mm) stone chippings, lightly rolled into the bitumen/tar.
8	Bitumen Slurry Seal Surface (and "Cape" Seals)	A seal consisting of fine graded aggregates (typically 10mm downwards), water, bitumen emulsion, cement, and sometimes an additive, mixed in a concrete mixer or other machine and spread on the road surface by hand or machine. Cape seals are combinations of Surface Dressing and Slurry Seal.
9	Clay Brick Surface	A layer of high quality clay bricks (typically each 10cm x 20cm and 7 – 10cm thick) laid by hand on a thin sand bed with joints also filled with sand and lightly compacted, or bedded and jointed with cement mortar.
10	Concrete Block Surface	A layer of concrete blocks (typically each 10cm x 20cm and 7 – 10cm thick) laid by hand on a thin (3 – 5cm) sand bed with joints also filled with sand and lightly compacted.
11	Plain concrete	plain mass concrete

[2] Blinding is a process of spreading smaller particle size material over a layer of large material up to a point where all the underlaying material's voids are filled.

No	Road Surface Improvement Options	Description
12	Bamboo Reinforced Concrete Surface	Jointed slabs of structural quality concrete reinforced with a mild steel rod grid. Joints with steel weight transfer dowels and bitumen seal.
13	Steel Reinforced Concrete Surface	Addition and mixing of a stabilizer such as lime, cement, or ion exchange chemicals, to a material to increase its strength and achieve the properties required of a roadbase. Mixing and compaction by light or heavy equipment.
14	Chemical or Emulsion Stabilized Roadbase	Roadbase mixed with chemical additives or bitumen emulsion
15	Natural Gravel Surface	A layer of compacted natural gravel wearing course (typically 15 – 20cm thick)
16	Lime Stabilization of Existing Surface	Addition and mixing of quicklime or hydrated lime to a soil or surface material, watering and compaction to increase its strength and reduce its susceptibility to the weakening effect of increasing moisture content. This is achieved by chemical reaction of the lime with the clay particles. Mixing and compaction by light or heavy equipment.
17	Dragging Road Surface	Smoothing out minor defects on an earth or gravel road surface and redistributing loose material on the surface, using tyre or blade drag.
18	Light Grading/ Reshaping of Surface	Minor reshaping of an earth or gravel surface to restore correct camber using labour or light/heavy grading equipment.
19	Dust proofing	Surface treatment with dust proofing materials
20	Improvement using Recycled Materials	Use of recycled road pavement materials, brick kiln waste, broken brick, demolition materials, industrial slags, etc.
21	Stone Chippings Surface	A layer of single sized (typically 20mm) crushed stone chippings.
22	Hand Packed Stone Surface	A layer (typically 20 – 30cm thick) of large broken stone pieces tightly packed and wedged in place with stone chips rammed by hand into joints, with remaining voids filled with sand. The Hand Packed Stone is normally bedded on a thin layer of sand/gravel.
23	Water Bound Macadam Roadbase	A layer of nominal single sized (typically up to 50mm) crushed stone compacted and fully blinded with well graded fine aggregate which is watered into the voids and compacted to produce a dense stable material. Layer thickness up to twice the nominal stone size. Material may be hand or machine crushed and laid.
24	Dry Bound Macadam Roadbase	A layer of nominal single sized (typically up to 50mm) crushed stone compacted and fully blinded with angular sand or fine crushed stone material which is then vibro-compacted to produce a dense stable material. Layer thickness up to twice the nominal stone size. Material may be hand or machine crushed and laid. Suitable in areas short of water.
25	Crushed Stone Roadbase	A layer (usually up to 20cm thick) of graded crushed stone material (typically 50mm downwards) usually derived from fresh sound quarried rock, boulders or granular material. The angular material derives its strength primarily from mechanical interlock. Material may be hand or machine crushed.
26	Mechanically Stabilised Roadbase	Addition and mixing of granular material such as crushed stone or sand to a material to increase its strength and achieve the properties required of a roadbase.
27	Dressed Stone Surface	A layer (typically 15 – 20cm thick) of stone blocks cut (dressed) to a cubic shape by hand, laid by hand. Joints mortared/sealed or tightly packed and wedged with stone chips rammed into place with remaining voids filled with sand. The Dressed Stone is normally bedded on a thin layer of sand/gravel.
28	Stone Sett Surface (Pavé)	As dressed stone, however stone blocks are smaller; typically about 10cm x 10cm x 10cm with mortared joints.

Further summary details are provided in Appendix B in Tables B-1 and B-2..

4.3 Factors to Consider in Decision Framework

The decision framework needs to take into account the full implications of the choice of surfacing type. The major issues for consideration are discussed in the following sections. It should be noted that any one, or the combination of these factors may determine the surface type required.

4.3.1 Climate, Geology and Topography

Prevailing climate, in combination with the geology and topography, could be the most significant factors influencing the selection of surface type. They also have a major implication on the construction and maintenance requirements of paved and unpaved roads. Some climatic and geological conditions may render an option unpractical. Some examples of adverse combinations of climate, geology and gradient condition are:

- Very wet climatic conditions in combination with clayey materials;
- Dry conditions in combination with sandy material which causes high dust generation and loose sand;
- Steep gradients combined with wet weather; and,
- Periodic flooding combined with unsealed surface.

Any road network fails in its purpose when it cannot provide acceptable access. There would be instances such as disastrous climatic events (e.g. tsunamis and hurricanes) that will lead to the destruction of any road, regardless of its surface. However, assuming normal (i.e. typical for the given area) weather patterns, the surface material should ensure a reasonable service level in terms of accessibility. Regardless of the surface type, effective drainage provisions are vital in ensuring the performance of the road under wet conditions. It is often the interaction of water, within and adjacent to the road pavement/surface that has an overarching impact on road performance.

Beside the above factors, many other issues might have to be considered, depending on the local conditions and circumstances. A decision framework, as described in the following section, offers guidance through the various factors.

4.3.2 Environmental and Socio-Economic Impact

In its broadest sense the environment includes ecological, economic, social and physical aspects (SATCC 2003). The key elements of the broadest definition of environment are summarised in Figure 4.2.

E N V I R O N M E N T	• Ecological	– Impact on flora and fauna – Deforestation – Disturbance of natural eco-system – Decrease in bio-diversity – Threats to exotic and non-indigenous species – Depletion of scarce material resources – Regressive or progressive soil erosion
	• Economic	– Capital costs (design and construction) – Maintenance costs – Flood damage costs – Loss/degradation of agriculture/arable land – Sterilisation of land for future use – Land value reduced (designated borrows, severed farms)
	• Social	– Severance/dislocation of local communities – Adverse impacts on women – Destruction of cultural antiquities – Conflicts arising from changing land use/ownership of land – Traffic accidents – Health and safety (e.g. danger to humans, especially children, and wildlife from drowning in borrow pits) – Construction impacts
	• Physical	– Aesthetic – e.g. loss of natural beauty and scars on landscape – Natural vegetation is not, or cannot, be replaced – Noise, air, water pollution – Dust impact – Disruption of drainage courses

Figure 4.2 Cornerstones of the environment (SATCC, 2003)

One of the most critical – and largely unappreciated - properties of unsealed roads is the use and depletion of natural resources. As road surfaces erode due to traffic and the environment, they need to be replaced. The replacement of road surfaces is particularly critical for gravel roads that require better quality or engineered material. The gravel layer typically erodes within 5-10 years and needs complete replacement. The replacement of gravel is both a financial and an environmental burden. If the eroded gravel is not replenished, the full investment can be lost within 3-7 years time.

In the future the pressure on the environment will become increasingly important during the surfacing decision process. Likewise, socio-economic factors are also becoming a major driving force in the selection of surfacing alternatives. It is recognised that through engineering projects significant changes can take effect within a community. It has been experienced that roads in particular could have a significant influence on the regional development. Some considerations related to the socio-economic development include:

- The presence of pedestrians, bicycles and other forms of non-motorized traffic;
- Contribution to regional development must be optimised through development of local industry and agriculture, and the transfer of technology and skills;
- Long-term maintenance needs are to be estimated and assured; administrative/financial constraints need to be considered and the sustainability of road maintenance must be ensured;
- Impact of improved transport (speed, accessibility) on industry development;

- User costs are to be kept at reasonable level. These must be commensurate with the socio-economic environment;
- Road works have been traditionally the first sign of, and also the first step towards economic improvement. The potential impact on poverty alleviation must be considered; and,
- The creation of employment.

The social impact of road provision and/or improvements on the social well being of communities is significant. It is not that visible within developed areas since well functioning infrastructure may have been in place for a long time. However, in some developing areas, the social impact due to road provision or improvements is substantial. RuralNet (2004) proposed methods to value the impact of infrastructure improvements based on the social impacts on the community. In this study it has been demonstrated how the up-grading of the Chinjala Road (See Figure 4.3) has changed the utilisation of the road and as a result impacted the community. This road has been upgraded by labour based methods and has resulted in an immediate impact on the traffic flow. After the upgrading, more than 20 bicycles have been recorded daily where there was none prior to the upgrade. This example further highlights the benefits of a road upgrade for non-motorised vehicles.

Figure 4.3: Chinjala Road, Zambie – Last maintained 10 years ago (RuralNet, 2004)

The social impact because of the transport interventions considered in this study is summarised in Table 4.3. In general, most social benefits resulted from better access and increased mobility for the community. Some disadvantages recognised were associated with increased safety concerns, both for vehicles and for pedestrians. Increased dust was also highlighted as a concern.

Table 4.3: Social Impacts of Transport Interventions – Zambia (RuralNet, 2004)

	Kawama (well connected)		Makangila (Remote)	
	Advantage	Disadvantage	Advantage	Disadvantage
Adult men	Trips to places e.g. trading places have reduced, able to travel out of the village and back the same day	Too much dust on the road causing environmental problems	Trading has become easy	Has opened access to the area for thieves
Adult women	Women are able to use bicycles to get to various places.	Women cyclists are vulnerable when they meet male cyclists	Find it safe now to travel on the road	non availability of public transport in the area
Male youth	The road has provided access to other villages where they go to look for employment	They tend to over speed causing accidents	Are now confident to travel to town either walking or riding	A lot of accidents with bicycles
Female youth	Road has improved access to the market where they go to buy vegetables and other food	Forced to walk to such places due to traffic congestion (bicycle) on the road	The road has made them more secure to travel to social places on their own	The road has made them to be more outgoing
Male children	They are able to go to school on their own because the road is now open and safe.	They play on the road and hence are involved in accidents	No impact	No impact
Female children	They go to school on their own	Play in the road and cause accidents	No impact	No impact

4.3.3 Safety

Safety considerations are not strictly part of the purpose of this document. However, these cannot be ignored when discussing significant change in the mode of operation of a road. Safety considerations are particularly important in the light of international studies that indicate an alarmingly high level of fatalities in developing countries Figure 4.4. Typically, fatality rates are 30-40 times higher in developing countries than in the developed countries.

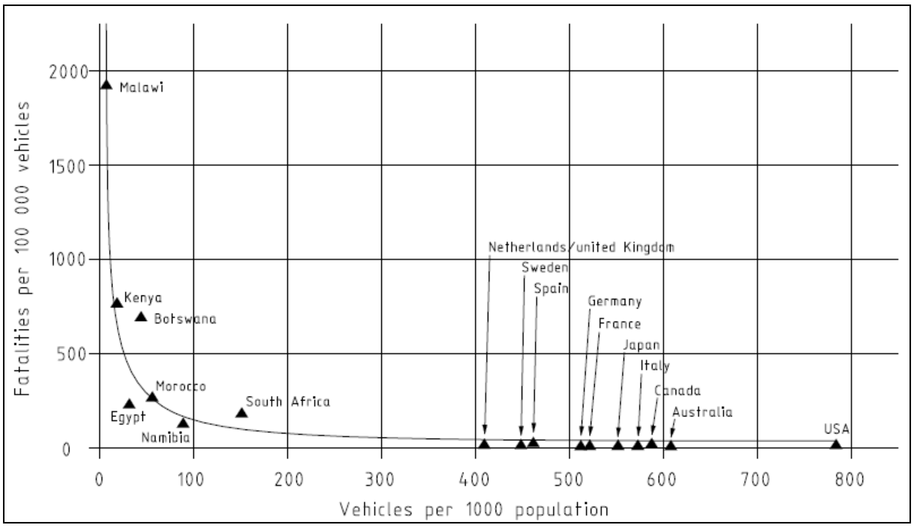


Figure 4.4 Fatalities per 1000 vehicles (SATCC, 2003)

The high fatality rate can be related to a number of causes, mostly to human factors associated with driver behaviour, mixed motorised and non-motorised traffic, and the changed speed conditions on a sealed surface. Overloaded vehicles also increase the accident rate. Safety issues must be considered during the design period as well as during operations. An example for safety guidelines during design is shown in Figure 4.5.

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

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

Figure 4.5 Key principles for designing safe roads (SATCC 2003)

4.3.4 Engineering Suitability

Most **developed countries** would have a surfacing option decision framework implemented that relies strongly on engineering considerations. Some of the factors considered under engineering suitability would include:

- The selected pavement type must be appropriate for the current and forecast traffic volume and composition;
- Materials and technologies must be locally available and appropriate;
- The formation and alignment of the road must be commensurate with the terrain and weather conditions; and,
- The selected pavement type must be consistent with the available construction and maintenance budgets and capacity, and be sustainable in the future.

Further considerations should be added for developing and emerging countries:

- Surface selection should recognise the prevailing quality assurance and testing environment and should consider tolerance of any risks of poor construction practices/quality; and,
- As truck technology steadily improves and local vehicle capacity adaptation occurs, the risks of damage by overloaded trucks is a particularly important factor for rural roads in an environment of unrestricted access and lax loading control. Some surface options are more tolerant of overloading than others (MRD & MPWT 2004).

For **developing countries** some of the factors above would have greater importance than others. For example, the capability/sustainability of the network maintenance would be one of the most important deciding factors for surfacing options.

One solution to this issue is to provide a more erosion resistant surfacing or wearing course. Whilst reliable technologies and materials are abundantly available, most of these require skilled labour, capital intensive equipment and high quality or engineered materials. These are rarely available in the rural areas of developing or emerging economies at a reasonable price, which would make these technologies inappropriate.

Even when funding is available, the use of these technologies is hampered with local problems, such as lack of skilled labour, long – and consequently slow – supply chain to support machinery, long hauling distances and lack of means to provide long term maintenance, just to mention a few. In addition, imported advanced technologies contribute very little to regional development when there is a substantial disparity between local skill levels and those demanded by the technology to be used. A focus on the use of the range of locally available resources is essential for these circumstances.

4.3.5 Durability of surfacings

The durability and service life of the selected surfacing technology is a critical aspect when committing funds to any particular solution.

The life expectancy of the pavement will depend on a number of critical factors, such as volume and composition of traffic, environment, design and work standards.

- **Volume and composition of the traffic** is one of the most critical factors determining the service life of the pavement. Light pedestrian and non-motorised traffic will imply a longer service life than mixed motorised traffic with occasional heavy vehicles. Past and even current traffic patterns are not always indicate future traffic reliably, as better quality roads usually attract higher traffic volume or heavier vehicles. The increased traffic volume and changed composition of the traffic needs to be considered. This is particularly important, when alternative routes are available at lower service level. These might be abandoned or became less preferred routes and thus traffic is channelled to the surfaced routes.

- **The environment** plays a critical role in the durability of surfacings. The impact of the environment will depend ultimately on the degree the environmental conditions were taken into account when designing the road (i.e.

soil and weather conditions). As it is unlikely that high design standards are applied, the selected surfacing on its own has to withstand the forces of nature. When extreme conditions are likely, sustainability and easy replenishment of the surfacing material will have to be considered even at the cost of higher service level.

- **Design and work standards** are critical to the service life of the pavement. For low volume or unsealed roads, it is usually assumed that marginal materials are used together with labour with low level of skills. Consequently, when estimating realistic service life, the lower end of the estimated range must be considered.

4.3.6 Failure modes of treatments

Each treatment may have several failure modes, depending on the environment, traffic, materials used and construction practice. The likelihood of typical failure modes for each treatment type is summarised in Table 4.4. It must be emphasised, that pavement failures usually appear in combination and are typically the result of several causes. The likelihood of each failure mode is tied not only to the material type, but it is obviously a function of several accompanying circumstances. This is particularly valid for structural failure modes. The "structural" column in the table below reflects also the sensitivity of treatment types to loading. For example, a rigid pavement (such as concrete) could be more sensitive to overloading than a flexible or unbound pavement.) Typically, pavements for low volume roads are not designed to meet structural strength criteria, but reflect local experience. See Appendix B for typical performance of surfacing options.

Table 4.4 Likelihood of failure modes

Pavement type	Material	Corrugations	Potholes	Rutting	Erosion	Ravelling	Dustiness	Structural
Bound	Concrete	low	low	low	low	low	low	high
	Bituminous	low	medium	high	low	low	low	medium
	Other treated	low	medium	high	medium	medium	low	high
Unbound	Natural	high	med	high	high	high	high	medium
	gravel	high	high	high	high	high	high	low
	rock/stone	medium	medium	medium	medium	medium	medium	low
	Block	low	low	low	low	low	low	medium

4.3.7 Political and organisational issues

The road managing authority and organisation(s) create the operational framework and environment. The operational environment includes the legislative, funding and maintaining conditions that all play defining roles in the design, construction and maintenance of the road. The main functions of the organisational environment: (After SATCC, 2003)

- Allocate responsibilities for road funding and maintenance;
- Establish accountable road authorities;

- Adopt commercial management practices to foster institutional, economic and technical efficiency;
- Adopt appropriate financial principles and practices;
- Dedicate revenues, and;
- Identify suitable funding sources.

4.3.8 Design Standards

Geometric design presents a unique challenge as the relatively low traffic volumes make design standards normally applied to higher volume roads less cost effective. Also, mixed traffic presents another level of challenge that is not addressed in the design standards developed for higher traffic volume roads.

In the absence of locally relevant design standards some standards may be imported. However, the original intentions and underlying assumptions of these standards must be taken into account when adopting any of these. (Typically developed countries produced design standards for low traffic volume roads. These usually assume a high labour cost and high technology environment). Some of the available design standards are listed below.

Table 4.5 Available Geometric Design Methods (SATCC, 2003)

Design Guide/Manual	Degree of Use		
	High	**Med**	**Low**
USA			
• AASHO:			
– A Policy on Geometric Design of Rural Highways (1965).	X		
• AASHTO:			
– A policy on Geometric Design of Highways and Streets (1984).	X		
– Guidelines for Geometric Design of Very Low volume Local Roads (AADT<400) (2001).			X
Australia			
• NAASRA:			
– Interim Guide to the geometric design of rural roads (1980).		X	
• Austroads:			
– Rural Road Design: Guide to the design of Rural Roads (1989).		X	
• ARRB:			
– Road classifications, geometric designs and maintenance standards for low-volume roads (2001).			X
United Kingdom			
• TRL:			
– Overseas Road Note 6: A guide to geometric design (1988).		X	
Southern Africa			
• SATCC:			
– Recommendation on Road Design Standards Geometric Design of Rural Roads (1987).		X	
• South Africa:			
– G2 – Geometric Design Manual (South Africa, 2003).			X
• Member states: Country manuals based essentially on one or other of the guides listed above.	X		

Geometric design standards define the framework for the layout of the road. These rules must address all key aspects of the operation and maintenance of the road, including safety and the environment. These are reflected through the adopted design speed, cross section, maximum gradient and curvature and safety features. These aspects are discussed in details in the documents referred above. The adopted design standards have a significant impact on the cost of the construction and maintenance of the road, hence adequate consideration is essential for the successful and cost-effective upgrade.

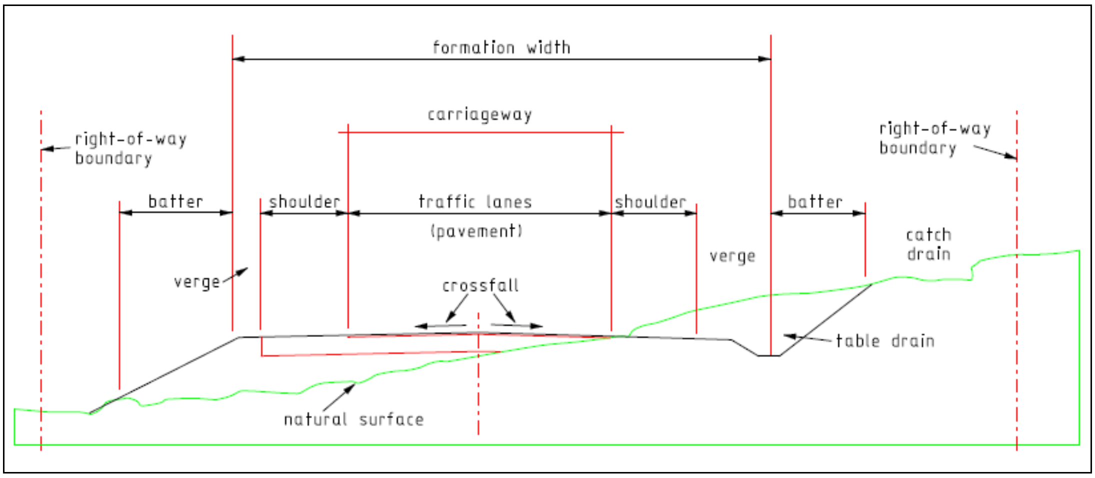


Figure 4.6 Typical cross-section elements (After Austroads, 2000)

4.4 Decision Process

There is considerable pressure on road agencies to provide sealed roads with permanent, all-weather surface. The benefits of a sealed road seem to be overwhelmingly convincing, but in reality sealing might not be the best economic option for the road users (both motorised and non-motorised) or the maintaining agency.

The decision to seal a road is a matter of trade-offs. Some of the benefits of sealed roads are obvious:

- Improved comfort for pedestrians, bicyclists and other non-motorized traffic;
- All-weather surface ensures access at all time;
- Sealing protects the base and sub-grade;
- A larger variety of vehicles can use the road;
- Higher travel speeds increases transport efficiency as the travel time is reduced; and,
- Maintenance cost may be reduced for some surfacing options.

However, sealed roads also have disadvantages that may make them inappropriate for low traffic volumes or under certain socio-economic conditions. There are a number of issues for consideration:

- The sum of design, construction, and maintenance costs of a sealed road are likely to be higher;
- Some sealed roads could be less tolerant to overloading from heavy vehicles. Once damaged, repair may be more costly and requires skills and equipment not always available;
- A neglected gravel road can be reinstated at relatively low cost, a deteriorated sealed road may require full reconstruction; and,
- Accident rate and severity may increase, generally as speed increases.

4.4.1 Example of Decision Processes

An example for the general decision process is given in Figure 4.7. The flow chart depicts a generic decision model that is valid for the overall process. The details of the process are discussed in Section 4.3.

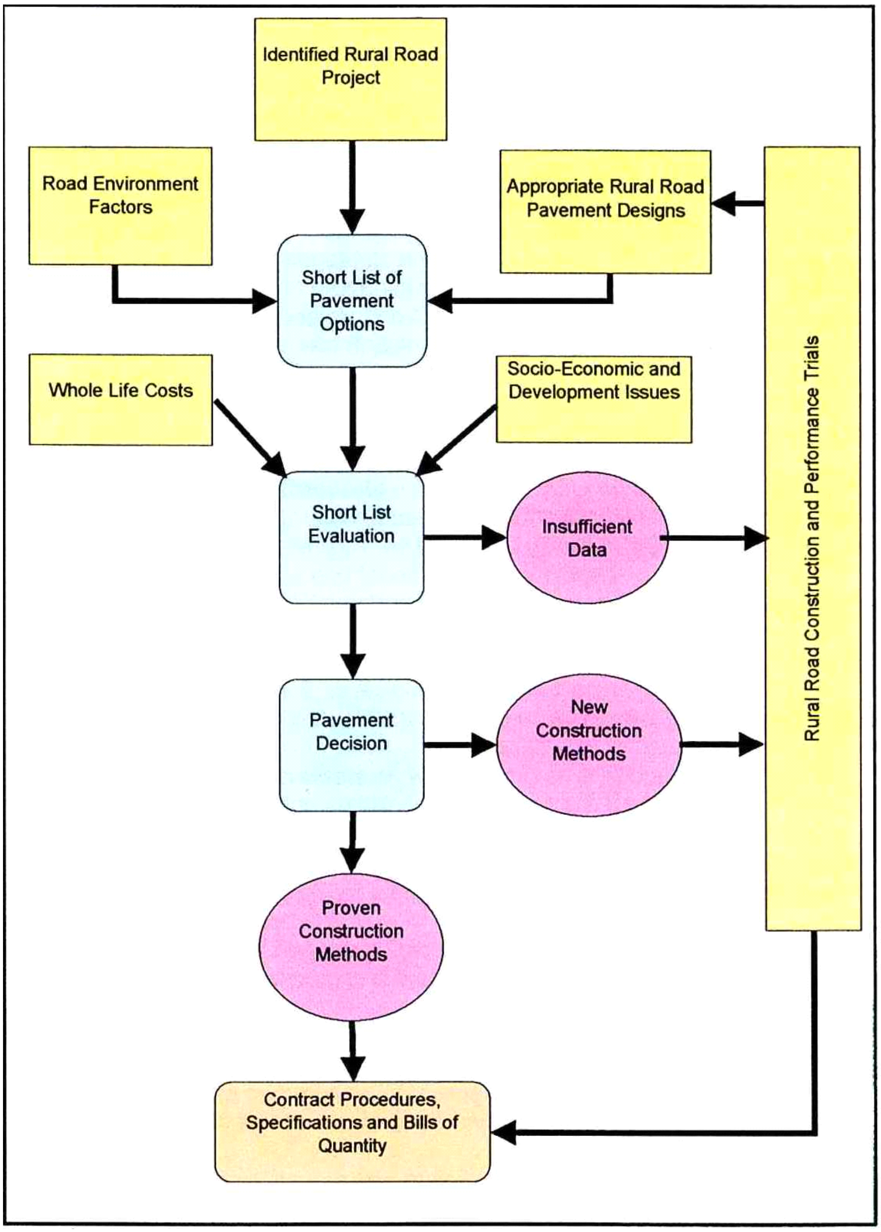


Figure 4.7: A Decision Process as proposed by Intech/TRL (2003)

Table 4.6 presents considerations as suggested by U.S. Federal Highway Administration (FHWA (2000) for considering sealing an unsealed road. Whilst this process is more detailed, in principle it follows the generic process shown in Figure 4.7.

Table 4.6:Considerations for Upgrading Unsealed to Sealed Road (FHWA, 2000)

Number	Item	Comments
1	Develop a road management program	Requires knowledge of the road, future traffic composition and maintenance costs. The overall needs and priorities are established
2	Ensure commitment to maintain the sealed road	Some sealed roads are more sensitive to maintenance (or lack of), and are far less forgiving for neglect. Consequently, sealing should be undertaken only when the long term commitment for sealing is made.
3	Check demand	Traffic below 50 vpd does not economically justify sealing. Between 50 and 500 vpd sealing is usually considered. The traffic composition must be taken into account; if overloaded trucks will frequent the roads a well maintained gravel surface might be cheaper to maintain than a sealed surface.
4	Adopt appropriate standards	Standards cover not only the level of service but the geometric and material requirements considered desirable. Sealing usually requires the revision of the alignment and drainage. Consequently, the collateral works may far exceed the costs of the sealing itself.
5	Consider safety	On sealed roads the travel speed is significantly higher than on unsealed roads (typically 90-110 km/h as opposed to 40-60 km/h). The higher speed must be met with higher design standards, considering such as sight distance, alignment, lane width, surface friction, super elevation. In many cases widening may be required at additional cost, including rebuilding drainage and widening bridges and other structures.
6	Upgrade drainage and road base	The drainage upgrade is necessary to protect the road investment. The base upgrade is usually required due to the gravel surface. The latter has a grading, geared towards retaining some moisture. This is a completely different requirement from that of a road base, which is supposed to drain moisture and not to retain it for dust suppression.
7	Determine costs	Beside the construction and engineering costs, estimate the maintenance cost over say a 5 years period then calculate the total cost (preferable as present value). The preparation costs should also be included, such as clearing, additional land acquisition, widening etc. Alternative options should be considered. The base option is the status quo, while any upgrade is considered an alternative.
8	Compare costs	User costs may be estimated from published data. User cost comparison will give an indication of the benefit of the sealing for the road users.
9	Decide	Select the technically feasible option with the lowest life cycle costs.

The above process reflects a strong engineering and management environment, where technology and analytical tools are in easy reach. Some other, unquantified aspects also need consideration when sealing an unsealed road is considered, such as:

- The benefits to pedestrians, bicyclists and other forms of non-motorized traffic;
- Beside the economics of road maintenance and motorized user benefits, a number of other environmental and political factors need to be taken into account, depending on local policies, conditions and capabilities;

- Dust reduction or elimination has significant benefits for the agriculture and environment. Human and animal health, safety, adjoining crops all benefit from a sealed – dust free – road. The benefits are difficult to quantify, but still need to be considered as a qualitative factor;
- Local policies on development, sustainability, environment, employment and local enterprise encouragement may favour certain upgrading options. For instance natural gravel is a limited, non-renewable resource and hauling material for regular regravelling over long distances can cause damage to haul routes. Significant costs are often spent on imported transport components (plant, vehicles, and fuel). In contrast, labour based stone paved roads can utilise local stone and community labour, transport and hand tool production resources and recycle up to about 85% of the construction costs in the community economy, supporting poverty reduction policies and initiatives;
- Traveller comfort is higher on sealed roads and so is traffic. This may result in increased accident rate, due to higher speeds. The design standards become a decisive factor in combating accidents;
- Maintenance resources and capacity can be extremely constrained in some developing and emerging countries, particularly in more remote locations. A realistic assessment of the situation should be made and the consequences and risks of failure to achieve maintenance should be considered in both the base and do-something scenarios;
- Upgrading resources may be limited or time-constrained. It is often not necessary to apply the same engineering or surfacing standard to the entire length of a route. Spot improvement (differential upgrading) or stage construction strategies may be the best use of limited or time-constrained resources; and,
- Sealing the road may attract more traffic; the road may be used by travellers otherwise using an alternate route; tourists may also be attracted. This in turn may raise the expectations for traffic signs and roadside furniture and services.

The qualitative factors may be taken into account in a scoring system (ARRB 2000 / Western Bay of Plenty District, 1997). The Western Bay of Plenty District (NZ) approach is based on a range of selection criteria, such as traffic volume, exposure factor, impact on earnings and benefit/cost ratio (See Table 4.7). The maximum score is 100 points, which is summed up by weighting the individual factors. This system is very flexible and can be adapted to widely different conditions. The numbers assigned to the different impact earnings were based on relative comparisons of crop production close to unsealed roads versus those close to sealed roads.

Table 4.7 An example of a Scoring Decision Process (WBOP, 1997)

Attribute	Weighing (%)	Scoring points	Comments
Traffic volume	25	20 PCU =0 points 300 PCU = 100	Existing traffic counts are converted to passenger car units (PCU)
Exposure factor	30	Scoring points based on a formula that covers, occupied building/km and building offset from the road. (for calculation of points refer to reference given).	This is a measure of the dust effect based on building density and offset to the unsealed road.
Impact on earnings	20	Persimmons (frontage) 50/km Kiwifruit (frontage) = 16/km Citrus (frontage) = 16/km Other (frontage) =6- 0.4/km	This is to reflect the consequences of road dust on crops and animal health. It is based on the frontage of the crop.
Benefit/cost	25	B/C ratio of 1 = 50 B/C ratio of 2 = 100 (max value is 100)	Road user benefits and road costs discounted to present day values.
TOTAL	**100**		

ARRB's suggested methodology (shown in Figure 4.8) is based on benefit/cost calculation. The benefits include user costs, accident rates and travel time. This process is very objective and quantitative but leaves little room for taking other (e.g. social) benefits into account. In such cases a qualitative approach is necessary to account for social/environmental factors so as to complement the quantitative results.

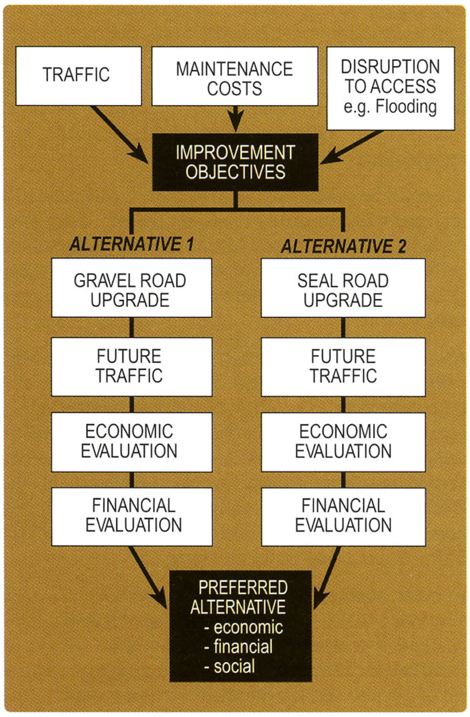


Figure 4.8: Example of a Surfacing Alternative Decision Process (ARRB, 2002)

4.4.2 Taking account of Non-Motorised Vehicles and Pedestrians in Economic Evaluations

It is recognized that traditional economic analyses do not generally adequately consider the benefits to pedestrians, cyclists and other forms of non-motorized traffic from sealing a road. Most literature related to the economic evaluation of non-motorised vehicles is aimed at assessing benefits of a modal shift in vehicle use. Typically these analyses are used in the promotion of non-motorised transport schemes such as cycle ways which consider benefits such as health, reduction in congestion and vehicle gas emission (Boulter, 2003). In the context of this report, though, the reader must consider economic benefits based on both motorised and non-motorised vehicles as a result of a change in road surface type.

In developing countries, the use of non-motorised transport fulfils an integral part of the socio structure of a community, because in some cases, there may be very little motorised vehicles using the roads. For example, the RuralNet (2004) study in Zambia illustrated that all of the four study regions had more than 75% non-motorised vehicles.

Table 4.8: Current Traffic Composition on Non Motorised and Motorised Transport- Zambia (RuralNet,2004)

Village	Composition of vehicles Current traffic Volume
Kawama	-10% heavy vehicles -15% cars and vans -75% non-motorised vehicles comprising bicycles and oxcarts
Mipundu	-20 % of motorised vehicles comprising of 1% trucks, 19% open vans and cars. -80% bicycles
Makangila	-13 motorised vehicles made up of only heavy motorised vehicles. -87% non motorised vehicles including bicycles and ox carts
Chinjala	There are no vehicles, just bicycles.

Another aspect to consider is that a change of surface option may also include a major road upgrade. Such and upgrade will completely change the usability of the road in terms of non-motorised vehicles. In the Chinjala example above, the road was unusable prior to the upgrade and bicycles only started travelling the road after the upgrade (See Figure 4.3).

Therefore, care must be taken in the calculation of economic benefits in cases of a large percentage or potential of non-motorised vehicles using the road. The benefits of the non-motorised traffic based on a change in surface type can be calculated according to PADECO (1996). The economic savings are calculated from time and operating cost of the non-motorised traffic and is calculated as follows (PADECO, 1996):

(i) NMT time and operating benefits due to normal traffic:

$$\Delta TOCN_{(m-n)} = \sum_{k} TN_k \left[TOC_{nk} - TOC_{mk}\right]$$

(ii) NMT time and operating benefits due to diverted traffic:

$$\Delta TOCD_{(m-n)} = \sum_{k} \left[TD_{mk} - TD_{nk}\right] \times \left[TOC_{nk} - TOC_{mk}\right]$$

(iii) NMT time and operating benefits due to generated traffic:

$$\Delta TOCG_{(m\text{-}n)} = \sum_{k} \{0.5[TG_{mk} - TG_{nk}] \times [TOC_{nk} - TOC_{mk}]\}$$

The summations are over all the NMT types (k = 1, 2, ..., K) specified by the user. The savings in vehicle operating costs is given by the expression:

$$\Delta TOC_{(m\text{-}n)} = \lfloor \Delta TOCN_{(m-n)} + \Delta TOCD_{(m-n)} + \Delta TOCG_{(m-n)} \rfloor$$

where $\Delta TOCN(m\text{-}n)$ = the time and operating benefits due to normal traffic of investment option m relative to option n

TNk = normal traffic, in number of NMT per year in both directions, for NMT type k International Study of HDM Tools Specifications for NMT Modelling in HDM-4

$TOCjk$ = the annual average time and operating cost per NMT-trip over the road section for NMT type k under investment option j (j = n or m)

$\Delta TOCD(m\text{-}n)$ = the time and operating benefits due to diverted traffic of investment option m relative to option n

$TDjk$ = diverted traffic, in number of NMT per year in both directions, for NMT type k due to investment option j

$\Delta TOCG(m\text{-}n)$= the time and operating benefits due to generated traffic of investment option m relative to option n

$TGjk$ = the generated traffic, in number of NMT per year in both directions for NMT type k due to investment option j

$\Delta TOC(m\text{-}n)$ = the savings in NMT time and operating costs due to total traffic of investment option m relative to option n.

5. Surfacing Alternative Decision Framework

5.1 Introduction and Objective of the Framework

As discussed earlier, unsealed roads dominate the networks of developing or emerging economies. The proportion of unsealed roads can be as high as 90 per cent, without counting the many unregistered unpaved roads. The choice of pavement and associate surfaces is not only a technical decision – it also commits the agency to a maintenance and renewal programme with substantial financial and social consequences. The immediate implication (construction cost) is highly visible, while the other consequences are less obvious, though as important as the construction costs. The surface decision framework therefore needs to be taken from a medium and long-term perspective.

The objective of the proposed decision framework is to assist road agencies to select the road surfacing most suitable for the local conditions and socio-economic environment. The intent is to guide the reader through the decision process by explaining the factors that influences it. A two-step decision process was developed to determine, firstly, whether changing the existing unsealed surface is required. Secondly, a decision matrix is provided should the outcome of the first step indicated that an alternative surface needs to be considered.

5.2 Upgrading of Unsealed Roads – The Need for Sustainable Strategies

The reader should be aware that the decision framework is not a simple choice between a surfaced and an un-sealed road. In fact, it is a continuum and the choice depends on a range of factors which are discussed in this section. It is often found that a road will go through a number of upgrading iterations during the use of the route (See Figure 5.1). Figure 5.1 shows some of the upgrading steps during the development stages of a route. Not all routes are developed according to all these stages since some routes will be constructed according to future needs.

For network managers it is important to know when it is the appropriate time to upgrade the road to a higher/more expensive road class. It is also equally important not to over-develop a road beyond the maintenance capability within an area. It is believed that it is worse to provide a community with access by means of a sealed road and then deprive them of it later (because of lack of maintenance).

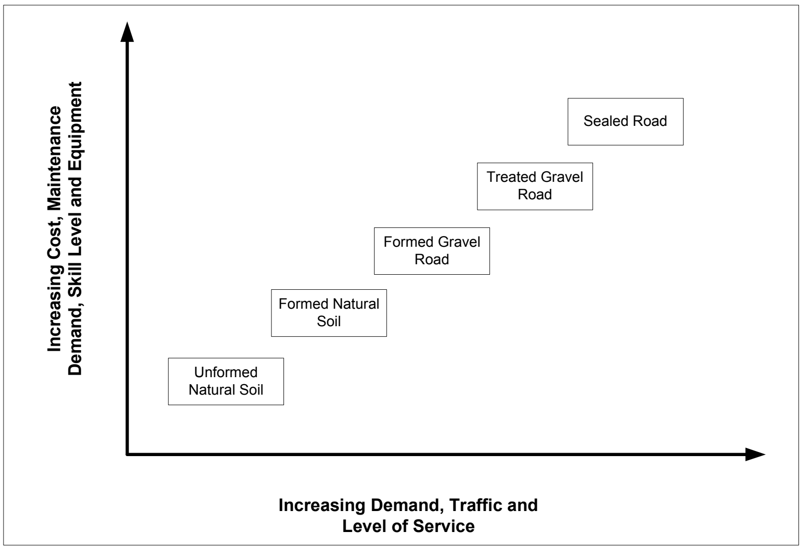


Figure 5.1: Upgrading Steps of Unsealed Roads

Upgrading of roads is often only viewed from a technical or engineering perspective. A more holistic approach **must** instead be used. For example, if it is decided to upgrade an unsealed road to a surfaced road, one has to be certain that the new surfaced road will be maintained during its useful life.

A framework for sustainable provision of low volume roads has been suggested in SATCC (2003). Figure 5.2 and Table 5.1 depicts the framework and list the factors that need to be considered. Although this framework has been developed for the over-all provision of low volume roads, it is equally applicable for considering the appropriate surfaces.

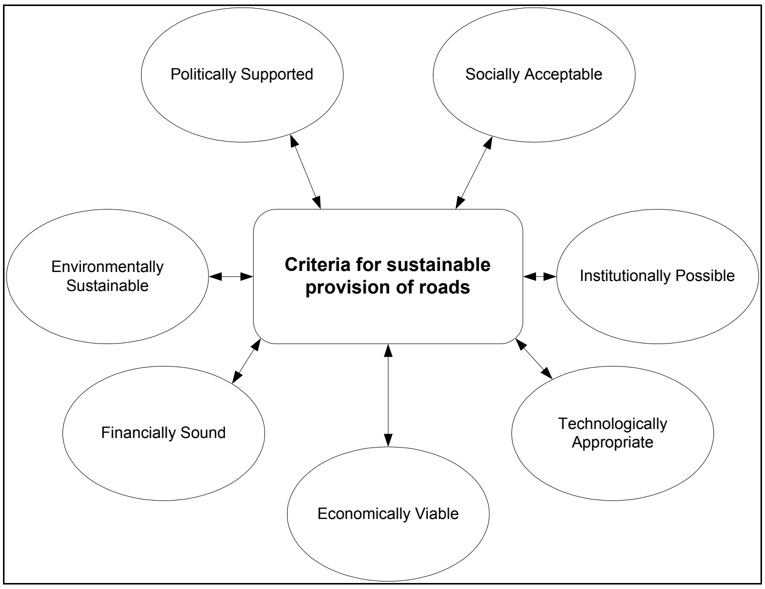


Figure 5.2: Proposed Framework for Sustainable Provision of Roads (based on SATCC, 2003)

Table 5.1: Factors Affecting the Provision of Low Volume Roads (based on SATCC, 2003)

Environment	Sustainability factors
• **Political**	**Government policy:** *Often no coherent policy in place.* • Need to highlight the key benefits to be derived from roads leading to the development of a comprehensive policy that: • Promotes sustainability in all aspects of roads provision • Covers wider social and economic goals of poverty alleviation by implication, employment creation • Promotes the use of appropriate technology as well as environmental awareness ***Political and public perceptions:*** *Tendency to favour conventional approaches and standards with perceived minimum "risk" attached to them.* • Need to maintain continuous dialogue with political and public stakeholders in order to: • Highlight pros and cons of alternative solutions in a balanced and transparent manner • More determinedly "sell" proven innovative approaches and appropriate non-traditional standards on the basis of quantified benefits.
• **Social**	***Social Issues***: *Tend to be neglected or to be subordinate to technical and economic issues:* • Adopt strategies that: o Support cost-effective labour-based methods of construction and maintenance o Ensure community participation in mainstream policy, planning and decision making o Eliminate gender biases and promote participation by women in labour-based activities o Promote activities and investment for sustainable enhanced livelihoods o Minimise the amount of resettlement and, where unavoidable, mitigate its effects by expeditious and compensated resettlement.
• **Institutional**	***Institutional capacity:*** *Often inadequate. Growing trend towards establishment of more autonomous central and local road authorities.* • Adopt strategies that: o Promote commercial management practices to foster institutional, economic and technical efficiency in the provision of roads; o Reduce and eventually phase out in-house, force account operations in favour of contracting out of works to the private sector o Define and develop an optimal environment for the development of local contractors.
• **Technical**	***Technology choice:*** *A wide range of options is available for designing, constructing and maintaining roads.* • Adopt strategies that: o Employ appropriate design standards and specifications o Utilise technologies that create employment o Use types of contract that support the use of local contractors o Promote road safety in all aspects of LVST provision.
• **Economic**	***Economic analysis:*** *Traditional approaches are often unable to capture the full benefits of LVST provision.* • Adopt strategies that: o Integrate social, environmental, and economic elements in project appraisal o Use appropriate evaluation tools capable of quantifying social, economic and environmental costs and benefits.
• **Financial**	***Funding:*** *Usually inadequate to meet minimum requirements.* • Adopt strategies that: o Promote commercialisation in the roads sector o Establish sustainable sources of funding
• **Environmental**	***Environment:*** *Generally regarded as the price to be paid for development and often neglected.* • Adopt strategies that: o Minimise the physical impacts of construction and maintenance o Take account of socio-cultural impacts (community cohesion) o Resource management (recycling of non-renewable materials)

	o Recognise that climate change should be taken into account in the design process.

5.3 Proposed Decision Framework

To assist in the selection of the most suitable surfacing option, a decision framework was designed. Beside the conventional economic and financial evaluation, a key feature of the decision framework is the inclusion of the socio-economic and environmental aspects critical for developing countries and emerging economies.

The framework comprises of three key steps:

1. Establish the demand for paved surface;
2. List suitable surfacing options for given circumstances; and,
3. Evaluation of surface alternatives, and the selection of the most appropriate.

The process can be applied to a complete road route, or to problematic sections within a network link as part of a differential upgrade strategy.

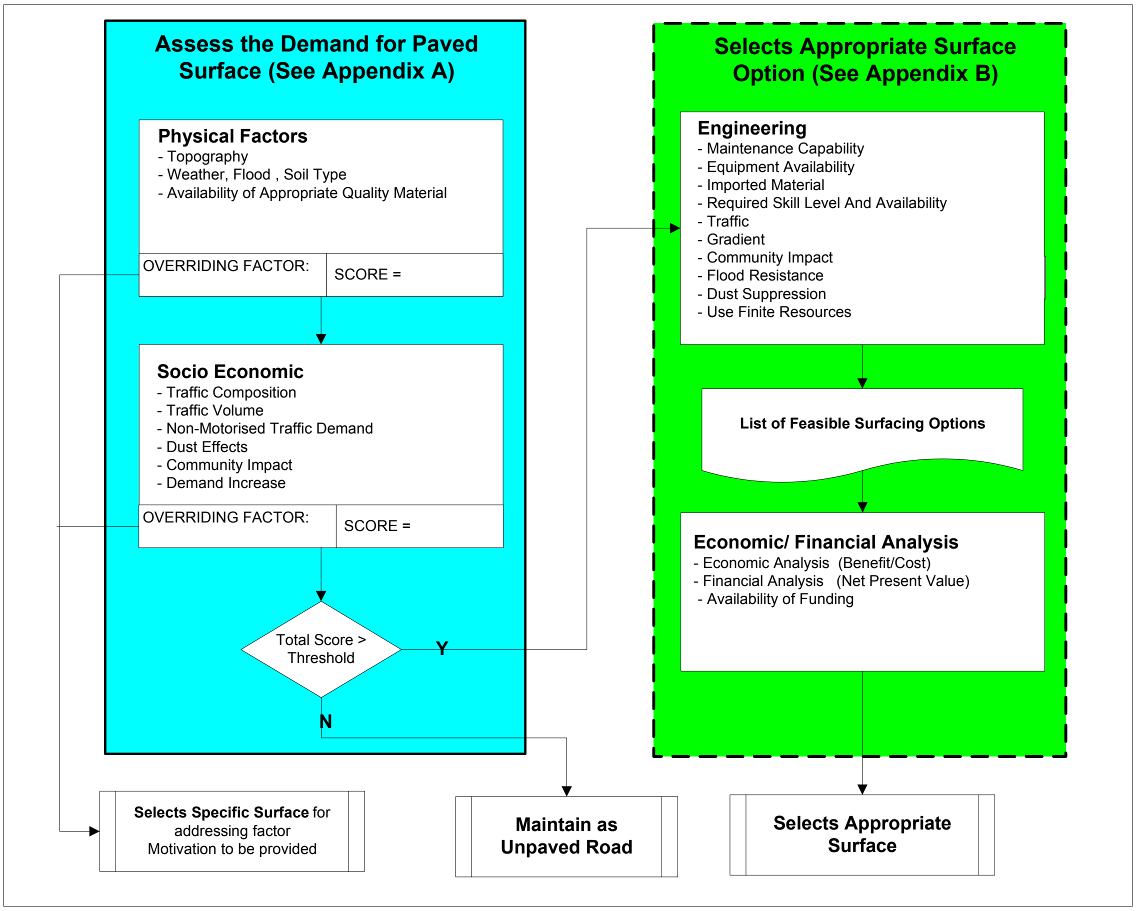


Figure 5.3: Graphical Presentation of Surface Alternative Analysis

Each step applies a different methodology to resolve the issue. The demand assessment process assigns scores to each critical aspect. The surfacing options are selected on the basis of engineering criteria, whilst the economic analysis includes present value and benefit cost calculation. Each one is discussed in the following sections.

5.3.1 Step 1: Assess Demand for Paved Surface

Under normal operational situations the network owner/authority will be aware of particular sections that are candidates for the upgrading to paved roads. Problems with access, extremely high maintenance cost, or public complaints indicate the need to upgrade an unsealed road. For cases where the need is clearly established, the first step (of assessing the demand) will not be required. However, if the network owner/authority is reviewing the status of all unsealed roads or if priorities need to be set, assessing the demands from the first principles is necessary.

A score sheet was developed to assist in evaluating the need to upgrade an unsealed road to a surfaced one. (Table 5.3 and Appendix A). The score sheet assesses both the environmental (climate/soil type and topography) and the socio-economic considerations affecting the decision to invest in the upgrading of the road. Overriding factors, i.e. circumstances that can override any other criteria can also be applied. For example, according to the socio-economic considerations dust on a particular road (or section of road) could be totally unacceptable – therefore this factor on its own can sufficiently identify this road as a candidate for surfacing.

The minimum score for an unsealed road to be considered for surfacing is illustrated in Table 5.2. The scores here should be considered as guidelines only. The trigger limit for surfacing might be adjusted to specific local conditions. This methodology allows a reasonable level of flexibility.

Table 5.2: Recommended Score System for Upgrading Unsealed Road to Surfaced Roads

Unsealed Road Network	Recommended Minimum Score (From Table 5.3 and Appendix A)
Developed Countries / Stable Funding Regimes	12-15
Developing Countries / Uncertain Funding Regime	16-20
Severely Under Funded Networks	21-30

Note: Some isolated factors may be taken into consideration to over ride the scoring system

Once a road has been identified as a candidate for surfacing, appropriate surfacing options are selected according to the following paragraphs.

Table 5.3: Scoring Sheet for Evaluating the Need to Upgrade an Unsealed Road

Physical Factors			
TOPOGRAPHY	**GRADE**	**SCORE**	
Flat or Undulating area	<4%	0	
Undulating to Hilly area	4 - 8%	2	
Hilly to Mountainous	8-14%	4	
Mountainous with steep sections	>14%	5	
FACTOR SCORE			
COMBINATION OF CLIMATE AND SOIL CONDITIONS			
Soils mostly suitable for prevailing weather (e.g. most soils are suitable in arid environment, except sand) and traffic		0	
Soils suitable for prevailing weather only if treated (e.g. stabilised)		3	
Soils predominantly are unsuitable as road surfacing for given climate (e.g. clayey material in wet, or sand in arid climate)		5	
FACTOR SCORE			
Socio Economic Factors			
NON-MOTORISED TRAFFIC DEMAND FOR SURFACING			
Animal or non-motorised traffic with low volume/demand for sealed surface		1	
Non-motorised traffic with medium volume/demand for sealed surface		3	
Non-motorised traffic with high volume/demand for sealed surface		5	
FACTOR SCORE			
MOTORISED TRAFFIC VOLUME (annual average daily traffic in both directions)			
< 50		1	
50 – 200		3	
>200		5	
FACTOR SCORE			
POTENTIAL IMPACT OF DUST FORMING			
Slight – minor agricultural area with scarce population		1	
Medium – agricultural area, low – medium density population		3	
Severe - major agricultural area, densely populated		5	
FACTOR SCORE			
COMMUNITY IMPACT			
Slight – after sealing the road, trade opportunities will not change significantly or project will not create any local employment opportunities		1	
Medium – Some improvement is anticipated, some employment opportunities are created		3	
Severe – Significant improvement is anticipated or extensive employment opportunities are created		5	
FACTOR SCORE			
WILL TRAFFIC INCREASE AFTER SEALING			
Unlikely		1	
Some		3	
Likely		5	
FACTOR SCORE			
AVAILABILITY OF QUALITY MATERIAL			
Available and short hauling distance		0	
Available but hauling distance is more than 10km		3	
Suitable material is scarce or depleted		5	
FACTOR SCORE			
GRAND TOTAL			

Notes

Topography
The grade of a road has a profound impact on the economic use and maintenance of a road. Steep grades have increasing surface drainage requirements, as the damage caused by the flow of water escalates with increasing grade. At the same time, vehicles need better purchase on the ground to maintain safe passage. The steeper the road, the more justified it is to provide an all weather sealed surface. Grade may vary along the road. Therefore a selective, differential or spot improvement approach may be justifiable along a particular route.

Climate and Soil conditions
The combination of climate and soil together determine the extent of accessibility periods without a sealed surface. The same traffic volume may require a fully sealed surface under certain environmental conditions, while under other conditions an unsealed surface might be satisfactory.

Non-Motorised Traffic Demand for Surfacing

From a socio-economic viewpoint, non-motorised traffic demand can have significant influence on the selection of the appropriate surface type for roads. Traditional engineering economic approaches often neglected non-motorised traffic since it is difficult to calculate an equivalent "road user" cost for non-motorised traffic. The composition of the traffic also plays a major part of the decision process. For example, if the traffic predominantly consists of animal transport a rougher surface would be suffice compared to say draw card or push bike type vehicles.

Motorised Traffic Volume
Motorised traffic normally has higher requirements from the surface to ensure adequate friction and to keep user costs at reasonably low level. The safety and operating requirements are reflected in the scores for traffic volume.

Dust effects
Dust is a major health and safety hazard with detrimental impact on local agriculture. The scoring supports any improvement that can reduce the generation of dust:

Community impact
Road improvements generally assist the development of trade, agriculture and industry. The degree of impact is of course related to the density of population and several other factors. The impact of road improvement is scored according to the anticipated level of development in the community.

Material Availability

Material availability is often one of the overriding factors in determining suitable surfacing for unsealed roads. For example, much of Cambodia and Botswana is predominantly sand and assumptions that suitable material is available may not be valid. In these cases justification to seal roads with traffic volumes as low as 50 vehicles per day has been documented.

5.3.2 Step 2: Identify Surfacing Options

There are a large number of surfacing technologies available. However, not all of them are suitable for all conditions. An engineering evaluation of the local conditions and circumstances was developed to narrow the choices to the most suitable options.

The currently available technologies were discussed in Chapter 4.2 and the most commonly used options are listed in Table 4.2. The wide variety of possible treatments are condensed and summarised in Table 5.4. The combination and permutation of materials and technologies is large. However, major grouping according to the key material and technology is a reasonable summary of individual surface options.

The purpose of this chapter is to present a methodology and to encourage the reader to implement the concepts and principles to specific local conditions. Nevertheless, the summary evaluation presented here is believed to be universally appropriate. An expanded version of Table 5.4 showing specific examples is in Appendix B.

Depending on the level of detail of the analysis, the user could either use Table 5.4 or Appendix B for the evaluation. The applicable engineering items on these tables are selected based on local conditions and/or objectives. The surface options (say two to four options) that obtained the highest number of applicable aspects are then evaluated according to the economic considerations explained in Section 5.3.3.

The key evaluation aspects are discussed as follows.

5.3.2.1 Production and Laying Equipment

The demand for production and placement or construction equipment is identified separately, as it is a function of the materials used. Market availability and local costs of equipment are of course essential considerations in the selection and costing of viable options. Technical sophistication and available back-up support are also aspects of significance in developing countries. For example excavation (i.e. mining) of natural gravel may not need complex machinery. Stabilising or mixing often requires the use of specialist equipment, however adequate and simple tractor based equipment may be available in the agricultural sector. The complexity of technology is of course relative, and has to be interpreted in the context of local conditions There are two aspects to consider:

- The complexity of equipment required can be defined whether the equipment is of general or specific use. For example, a crusher and mining equipment can be used for many other construction projects beside road construction.
- The physical complexity of the equipment, i.e. the potential repair costs and delays need to be taken into account.

Sophisticated, high technology equipment methods can often be inappropriate for rural roads in developing and emerging countries because of considerations of high capital costs, high mobilisation costs, low utilisation, skill requirements, inadequate spares and technical support, high cost of finance, discontinuity of workload and risks.

Many of the surface options utilise labour methods and require only simple, low capital cost equipment such as small scale crushers (or hand crushing and screening), 1 tonne vibrating rollers, or concrete mixing and vibrating equipment.

5.3.2.2 Imported Material

Materials are deemed to be imported when they have to be hauled for a long distance and may require a specialist production line. Bitumen and cement are two examples of material that are normally imported to the vicinity of the road location. Steel reinforcement is also considered to be an imported material.

5.3.2.3 Skill Level

The required skill level is closely related to the selected technology. As guidance, skill requirements are defined as low if they can be acquired on the job within a short time. Medium level requires training and longer time on the job. High skill levels are usually associated with formal training and education. If local employment is desired, low to medium skill levels are usually preferred as opposed to the high skill level. Low skill requirement usually means immediate employment, whilst medium skill level can still be acquired on the job, but it usually can be utilised well beyond the local road construction. For example, block paving is a medium level skill that will remain with the trained staff and can be utilised for building and paving other areas than roads.

5.3.2.4 Traffic

Each pavement type has a different resistance to traffic. The traffic resistance of a surface must be considered in the context of the environment. Figure 5.4 provides a guide only – the classification in the figure is generally true, but needs adjustment to local conditions. The actual traffic volume and composition may also affect the classification. The incidence or risk of heavily (over) loaded vehicles must be assessed.

5.3.2.5 Gradient

Steeper gradients require good traction for the vehicles, higher resistance to surface wear and a higher level of stability from the surfacing material. Consequently, materials with low shear resistance (such as chip seal) may not be suitable for steep grades. On flat or undulating roads some of the benefits of a stronger surfacing might be wasted. Consequently, it is important that the vertical alignment and the chosen materials and technology are aligned.

Gravel should not normally be used on gradients greater than 6% (Millard 1993). However, in higher rainfall areas (>1500 mm/year), erosion may be excessive on gradients steeper than 4% (Intech-TRL 2005).

5.3.2.6 Employment Opportunity

Creating employment is one of the most important tasks of any rural road development. Besides providing transportation, i.e. a link to the larger economy, roads can also create local employment. Asphalt or automated concrete placement are very efficient technologies, but hardly create significant employment opportunities. On the other hand, hand laid stone macadam, dressed stone or block-paving can boost local employment.

5.3.2.7 Flood Resistance

Where floods regularly damage roads, a more robust and flood resistant technology should be selected. The alternative is to utilise a sacrificial surface, i.e. one that is so cheap that rebuilding is not much more expensive than the cost of building and maintaining a more expensive one. This aspect will be evaluated during the next phase of the assessment, i.e. during the economic evaluation phase.

5.3.2.8 Dust Suppression

Most sealed surfaces are reasonably dust free. However, some of the cheaper ones may not offer the same level of long-term dust protection than others. For specific dust suppression or dust palliative options the reader is referred to Table 4.1.

5.3.2.9 Use of Finite Resources

Local resources must be protected so their general availability can support sustainable development. A typical example of this issue is re-graveling. The excessive use of gravel may lead to the depletion of local resources, which may not be available when they are required for other purposes (such as general buildings or major road construction, etc). A more durable solution with maintenance requirements that do not endanger the environment are preferable.

Natural gravel suitable for road surfacing usually occurs in limited deposits the working out of these deposits will cause longer and more costly haulage for future regravelling operations. If gravel has to be hauled more than 10 km, then particular attention should be paid to analysing the initial and long term costs implications of gravel and other feasible surface options.

5.3.2.10 Maintenance Capacity

It is essential to make an assessment of the maintenance arrangements that will be in place to sustain any surface constructed under an upgrading initiative. The benefits of the upgrading will only accrue **IF** appropriate maintenance arrangements are in place to manage and implement the maintenance and that sufficient funding will be available. If there are deficiencies in maintenance capacity, it may be worthwhile to instigate improvements as part of the upgrading initiative.

5.3.2.11 Additional Factors to Consider During Assessment

There are a number of factors that need to be considered in conjunction with the factors in Table 5.4. These factors will have an influence on the decision process because it may influence the cost or the appropriateness of a particular surface. Some examples are indicated below:

Standards

A further consideration should be the geometric standards appropriate for the road link under assessment. Even the possibility of staged construction could influence surface option selection. For example, a rural community in Vietnam has selected a 1.4 metre wide concrete road for their self-funded village access; suitable for the predominantly motorcycle traffic, and allowing loaded motorcycles to pass safely. The construction cost was similar to a 3.5 metre wide crushed stone macadam surface. The lower maintenance burden was a factor in the consideration. Arrangements can be made to accommodate future widening of the pavement as resources become available in such circumstances.

Road bases, Sub-bases and Foundations

The various surfaces will need to be constructed on a suitable base and/or foundation layer. This ranges from merely the shaped and compacted in-situ, unmodified soil, through to a range of imported natural and processed materials such as natural gravel, crushed stone, and stabilisation techniques (Petts, 2002). This design consideration can influence the cost outcome of the selected surface option significantly.

Table 5.4: A Guide to Engineering Evaluation

Classification				Engineering Evaluation										
	Group name	Materials	Subgroup	Production Equipment requirement	Laying equipment required	Imported material required	Skill level	Traffic Capacity	Gradient Severity	Local Employment opportunity	Flood resistance	Dust suppression	Use of finite resources	Maintenance Liability
1	Macadam	Bituminous	crushed	high	medium	yes	med	high	steep	low	medium	high	low	low
2	Asphalt	Bituminous	mix	high	high	yes	high	high	steep	low	medium	high	low	low
3	Asphalt	Bituminous	mix/recycled	high	high	yes	high	high	undulating	low	medium	high	low	low
4	Seal	Bituminous	seal	high	low/medium	yes	med	high	undulating	Low/medium	low	high	medium	medium
5	Block	Clay Brick	dressed/block	low/medium	low/medium	yes	med	med	steep	high	medium	high	low	low
6	Block	Concrete	dressed/block	low/medium	low/medium	yes	med	high	steep	high	medium	high	low	low
7	Plain Concrete	Concrete	mass	medium	low/medium	yes	med	med	steep	high	high	high	low	low
8	Reinforced concrete	Concrete	re-enforced	medium	medium	yes	med	high	steep	medium	high	high	low	low
9	Gravel stabilised	Gravel	stabilised	medium	medium	yes	med	high	undulating	low	medium	high	medium	medium
10	Gravel	Gravel	natural	low/medium	low	no	low	med	undulating	medium	nil	low	high	high/very high
11	Natural stabilised	Natural	stabilised	medium	low/medium	yes	low	med	undulating	medium	low	medium	medium	medium
12	Natural	Natural	Soil	low	low	no	low	low	flat	medium	nil	nil	low	high
13	Natural treated	Natural	treated	medium	medium	yes	low	med	undulating	low	nil	high	medium	medium
14	Recycled	Recycled	stabilised	medium	medium	no	med	high	steep	medium	medium	high	low	medium
15	Stone/crushed rock	Stone	crushed	low/medium	low/medium	no	low	med	undulating	high	low	medium	medium	medium
16	Stone - block	Stone	dressed/block	low/medium	low	no	med	high	steep	high	high	high	low	low

5.3.3 Step 3: Financial and Economic Evaluation

Financial and/or economic analysis is usually conducted to rank the options according to their costs and benefits. Financial evaluation focuses on the cost of the project to the agency by comparing the construction and maintenance costs of the various options. The most commonly used financial analysis technique is life cycle costing, where all construction and maintenance costs occurring during the life of the road are taken into account. If the life cycle cost of a paved road option is cheaper than the long-term cost of an unsealed road, the upgrade is justified. This is subject to the availability of funds in the short term

Economic evaluation takes into account the total cost and benefits to the community. With the economic analysis the benefits (i.e. cost savings) for upgrading to a surfaced road are calculated in terms of the savings in agency (usually maintenance), road user, safety, productivity and agricultural costs. Table 5.5 suggest the appropriate analysis for different networks and funding regimes.

Table 5.5: Analysis to be used for Road Surfacing Decisions (Based on SABITA, 1992)

Road / Project	Appropriate Basis for Decision
Rural (locally funded) Private Roads Military	Financial Analysis
Urban/township Rural (Bank funded*) Nationally Funded roads Parks, forestry Socio-political decisions	Economic Analysis

Note* Bank: i.e. World Bank, Regional Development Bank or national funding agency

5.3.3.1 Financial Analysis

The inputs required for performing the financial analysis include:

- Discount Rate
- Traffic Volumes;
- Maintenance cost for unsealed option;
- Capital/construction cost for surfacing options;
- Maintenance cost for surfacing options; and,
- In some analysis the inflation rate is also included.

As the costs occur over time, costs must be compared at today's level, by considering inflation and the interest (discount) rate by calculating the Present Value. Based on the above factors the Net Present Value (NPV) is calculated for both the unsealed and the surfacing options. Appendix C explains the difference between Present Value and Net Present Value (NPV). A lower NPV indicates lower total costs, therefore the lowest NPV indicates the cheapest option. All surfacing options having a NPV lower than that of the unsealed road would be deemed eligible. The lowest NPV option would represent the financially optimum solution. The discount rate for the analysis must be representative for the region. Typical values vary between 8-10 per cent.

Both financial and economic analysis requires the accurate estimation of the performance of the pavement under local conditions. The life expectancy of the surfacing is highly variable due to construction quality, materials, possible traffic growth and environmental effects. It is therefore recommended that for each study area a surface life matrix be compiled based on local experience. An example of such a matrix is depicted in Table 5.6.

The table illustrates the expected surface lives for both urban and rural environments. It also differentiates the surface life expectancy according to the operating conditions of the particular road.

Table 5.6: Example Surface Lives Applicable for South African Conditions (Based on SABITA, 1992)

Surfacing	Urban Environment		Rural Environment	
	Poor Conditions	**Good Conditions**	**Poor Conditions**	**Good Conditions**
asphalt	10-14	15-20	10-14	15-20
double seal, cape seal	5-7	8-11	6-8	9-13
single seal	3-5	5-8	6-8	9-13
Sand seal				
Single	1-3	2-4	1-3	2-4
Double	4-6	6-10	5-7	7-11
dust palliative	1-3	2-4	1-3	2-4
Slurry				
thin	2-4	4-6	2-4	4-6
thick	4-7	7-9	4-7	8-10

Notes:
1. Poor conditions, means developing environments or problem areas such as weak pavement structure, poor quality control, poor drainage etc;
2. Good conditions, means a well resourced environment with no other problems;
3. Surfacing life is highly variable and this table is only a guide to life.

Based on the local conditions, surface performance and regional costs it is possible to determine the breakeven traffic volumes for different surfacing options and construction cost scenarios. An example of the outcome from such a financial analysis is depicted in Figure 5.4. Note the figure showing outcomes for different costing scenarios is categorised in five groups (x-axis). For example, at an average cost level the surfacing of unsealed roads becomes economical at approximately 250 vehicles per day. For this costing option it is also observed that the single, slurry and double chip seals have the lowest associated life cycle cost. A similar outcome can also be achieved for an economic analysis. Note that this particular example did not include the cost/benefits considerations from non-motorised vehicles. The social and non-motorised traffic benefits were accounted for according to a qualitative assessment of the appropriateness of surface options.

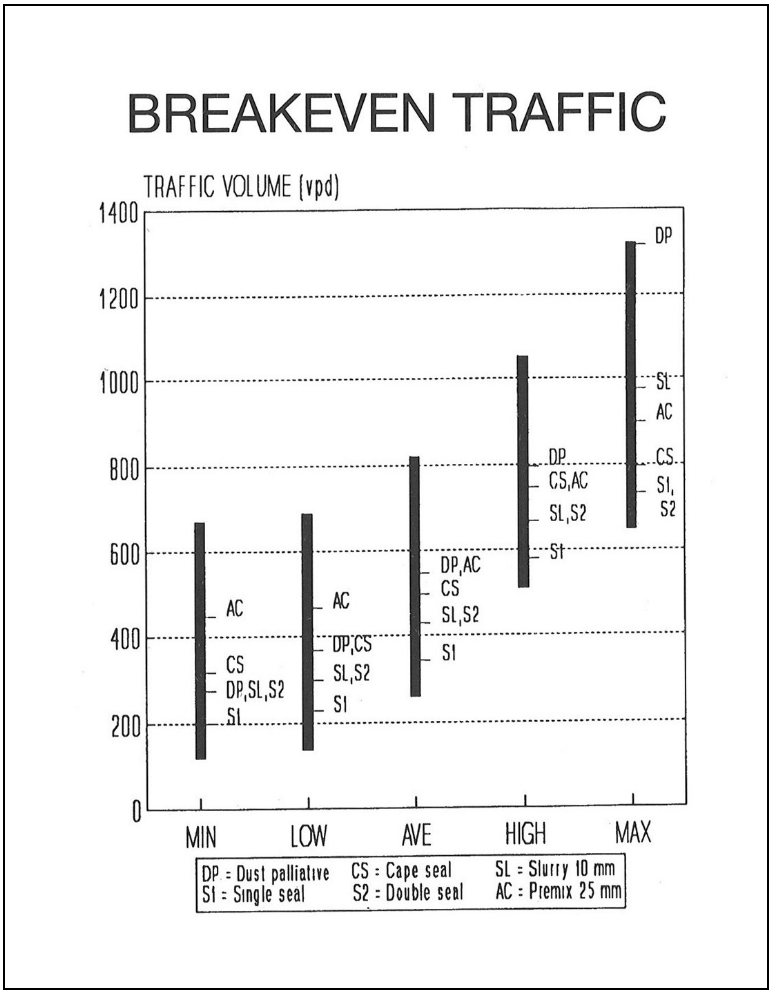


Figure 5.4: Example of Breakeven Traffic for Various Surfacing - Using Financial Analysis (SABITA, 1992)

Note: The five categories on the x-axes reflects different cost scenarios. These cost scenarios may be a function of availability of material, labour and construction technique.

Sometimes the financial and economic impact is not restricted to the road section under question. For example, when materials are hauled long distances for construction and maintenance (e.g. regravelling), there may be significant costs involved in the damage caused to haul routes, particularly in the wet season. In this example the impact on linking roads should also be considered.

5.3.3.2 Economic Analysis

The economic analysis mainly involves a benefit-cost (B/C) ratio analysis but for more complex systems incremental cost benefit analysis can also be undertaken. The Transfund (2004) Project Evaluation Manual defines the B/C as:

> "*The B/C ratio of a project is the present value (PV) of the public benefits gained divided by the PV of the road agency expenditure. A project is*

regarded as economical or worthy of execution if the PV of its benefits is greater than the PV of its cost. I.e. a project is economical if the B/C ratio is greater than 1.0."

In other words, the benefits must exceed costs. For most funding situations a B/C of one may not always be affordable so one invests in projects with B/C ratios greater than one. For such cases a minimum B/C ratio is defined and is used as a cut-off for substantiating any upgrading from unsealed to paved roads.

When comparing several options, the incremental benefit-cost ratio may give further indication of the relative benefits of the options. The incremental B/C gives the incremental benefits per incremental $ expenditure. The incremental B/C analysis is shown graphically in Figure 5.5. This figure shows two options under consideration. Both options (A&B) have more benefits compared to a do-minimum option but both options have higher cost also. During the analysis the highest incremental B/C is selected for the available funding. In this example, Option B will be selected for unlimited funding, but for any funding less than 1000 units, Option A will be selected. For any funding less than 400 units, the do-minimum will be undertaken. The incremental B/C is applied in a number of asset management software applications for the evaluation of maintenance options that include considering different surfacing options (Jones, et al, 2001)

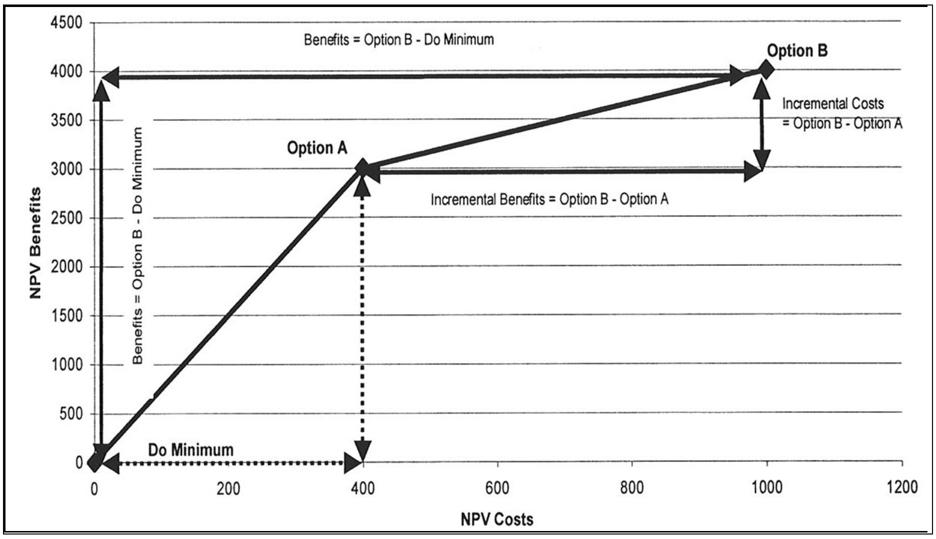


Figure 5.5: Example of an Incremental Benefit Cost Analysis (Transfund, 2004)

In order to perform any B/C type analysis the following information is required:

Benefits

All possible benefits that are experienced in upgrading the unsealed road to a surfaced road, need to be included. These benefits may include:

- Road user cost including:
  - Vehicle operating cost due to reduced roughness;
  - Accident cost;
  - Travel time cost

    - Passenger discomfort
- Non-motorised traffic benefits (See Section 4.4.2):
    - time cost of traveller;
    - operating benefits due to diverted traffic and generated traffic.
- Increased Agricultural Production
- Reduction in Whole of Life Cost

Vehicle operating cost costs (VOC) may be calculated according to VOC model as published in HDM-4 (Odoki and Kerali, 2000) and Archondo-Callao (1999). Accident costs can be calculated according to regional data and publications. Transfund (2004) suggests a further benefit of 7 US cents per kilometre for road user comfort. Increase in speed, and therefore reduction in travel time can be estimated based on Table 5.7.

Table 5.7: Increased Speed for Upgrading Unsealed to Surfaced Roads (Based on Transfund, 2004)

Unsealed Section **Mean Speed of light vehicles (km/h)**	**Surfaced Section** **Increase in Mean Speed (km/h) for increased road width (m)**		
	No Increase	**Increase of 1 metre**	**Increase of 2 metres**
> 60	0	5	10
45 to 60	5	10	20
35 to 45	10	15	25
< 35	15	20	30

The following benefits are recommended for reduced dust effects on Farms (Transfund, 2004):

- Beef and sheep farms $ US 35/km per annum
- Dairy Farms $US 85/km per annum
- Horticultural Land - $210/km per annum

Note these rates will be different for alternative countries/economies.

Some additional Information and typical values used during the economic analysis is provided in Appendix C.

Costs

The cost of the project is calculated according to the same principles as discussed in the previous section. The results of the B/C analysis can be compared by using a simple ranking system or alternatively using an incremental B/C process. From these analyses we can obtain the traffic breakeven points for warranting the upgrade from unsealed to surfaced roads. As an example Figure 5.6 (Gourley, et. al. 2002) was compiled using economic analysis that took new technologies and socio-economic considerations into account. The figure suggests enhanced performance of engineered earth roads plus surfaced roads become more cost effective due to alternative approaches. It illustrates the economic breakeven point from an earth to a gravel road to be at 100 vehicles per day and from earth to paved at 120 vehicles per day in the typical conditions analysed.

However, local factors will influence the relative positions of the curves, for example due to:

- Soil type;
- Gradient;
- Rainfall;
- Materials haul distance; and,
- Maintenance environment.

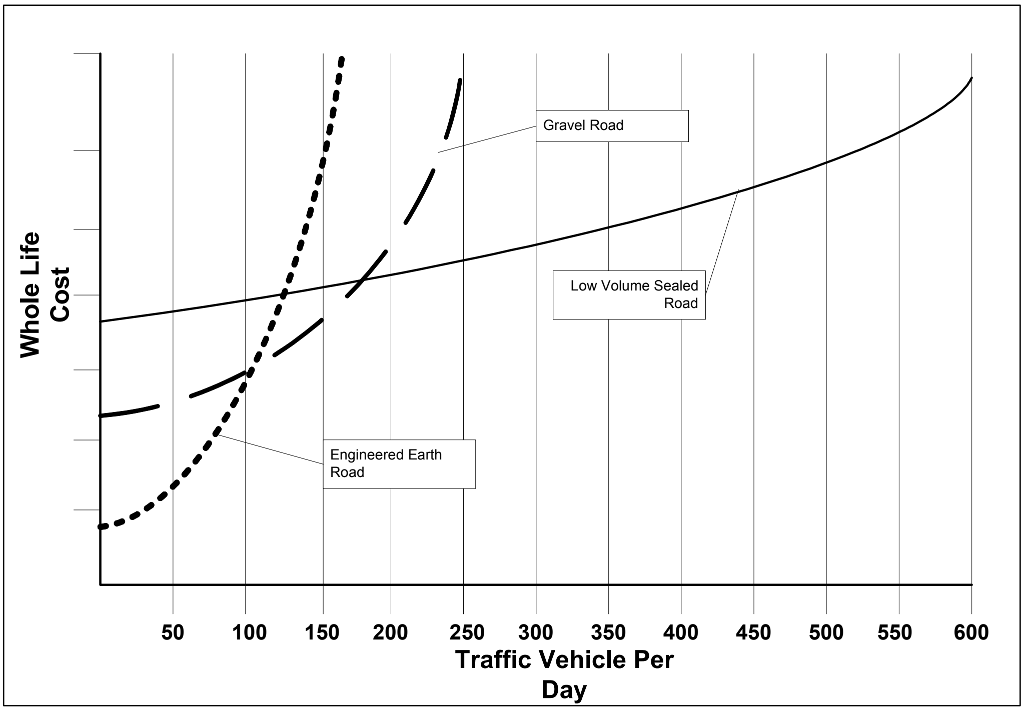


Figure 5.6: Economic Analysis for Upgrading Unsealed roads to Surfaced Roads (Based on Gourley, et. al. 2002)

5.4 Worked Example

5.4.1 Background to the Problem

An asset manager is managing a network which largely consists of unsealed roads (80%) and a limited number of surfaced roads (20%). On this network a road is going through an intensive farming area and there have been a number of requests to get the road upgraded to a surfaced road. The farmers made this request as the road is in bad condition as well as generating an unacceptable amount of dust.

The manager decided to use these guidelines for determining the best option for addressing the farmers concerns. The following sections document his process.

5.4.2 Step 1: Evaluating the Need to Upgrade to a Surfaced/Treated Road

The needs assessment was completed using the score sheet contained in Appendix A and Table 5.8 depicts the outcome based on the local conditions.

The score from the need assessment totals 27 and according to Table 5.2 there is a definite need to consider this road for an upgrade to a surfaced road.

Table 5.8: Need Assessment for Surfacing and Unsealed Road

Physical Factors			
TOPOGRAPHY	**GRADE**	**SCORE**	
Undulating to Hilly area	4 - 8%	2	
FACTOR SCORE			2
COMBINATION OF CLIMATE AND SOIL CONDITIONS			
Soils suitable for prevailing weather only if treated (e.g. stabilised)		3	
FACTOR SCORE			3
Socio Economic Factors			
NON-MOTORISED TRAFFIC DEMAND FOR SURFACING			
Non-motorised traffic with medium volume/demand for sealed surface		3	
FACTOR SCORE			3
TRAFFIC VOLUME (annual average daily traffic in both directions)			
>200		5	
FACTOR SCORE			5
POTENTIAL IMPACT OF DUST FORMING			
Severe - major agricultural area, densely populated		5	
FACTOR SCORE			5
COMMUNITY IMPACT			
Severe – Significant improvement is anticipated or extensive employment opportunities are created		5	
FACTOR SCORE			5
WILL TRAFFIC INCREASE AFTER SEALING			
Unlikely		1	
FACTOR SCORE			1
AVAILABILITY OF QUALITY MATERIAL			
Available but hauling distance is more than 10km		3	
FACTOR SCORE			3
GRAND TOTAL			**27**

5.4.3 Step 2 Identify the Surface Options

The table in Appendix B was used to identify the preferred surfacing options for this road by using one of the following:

- Continuing to maintain the road as an unsealed road;
- Treat the existing unsealed road with a Dust Palliative;
- Surface the road with a thin bitumen surface (e.g. Chip seal, Otta or Cape Seal).

The selection of the above surface types was based on the following main factors:

- These surface types are simular to surfaces used on other parts of the network, thus confirming the availability or required material, skills and equipment;
- Dust suppression was one of the main factors to address;
- The maintenance liability of these surface types are well within existing capabilities.

5.4.4 Step 3: Economic Analysis

Since the road is regionally funded, an economic analysis is required to select the most appropriate surface type from the option list developed in the previous sections.

The capital, maintenance and additional benefits are summarised in Table 5.9. This table has been compiled using typical costs obtained from Archondo-Callao (2004). The additional benefits shown in this table incorporated the savings experienced on the horticultural farms.

Table 5.9: Cost Streams for Each Surfacing Option

Option	Investment Cost ($/km)	Annual Maintenance Cost ($/km-yr)	Road User Cost ($/V-km)	Non-motorised Vehicle Costs	Additional Benefits ($/km-yr)
1. Maintain Current Unsealed	0	500	0.624	0.02	0
2. Treat with Dust Palliative	70,000	2,500	0.381	0.015	180
3. Upgrade to Surfaced (Say Otta Seal)[1]	155,00	1,900	0.271	0.01	250

Note 1 – For this example only one bituminous seal were tested. In reality all types of surfaces will be tested and according to the cost/benefit consideration each outcome will be assessed according to the available budget and engineering considerations.

Figure 5.7 illustrates the efficiency frontier for the three surfacing options (a traffic volume of 500 vehicles per day has been assumed).

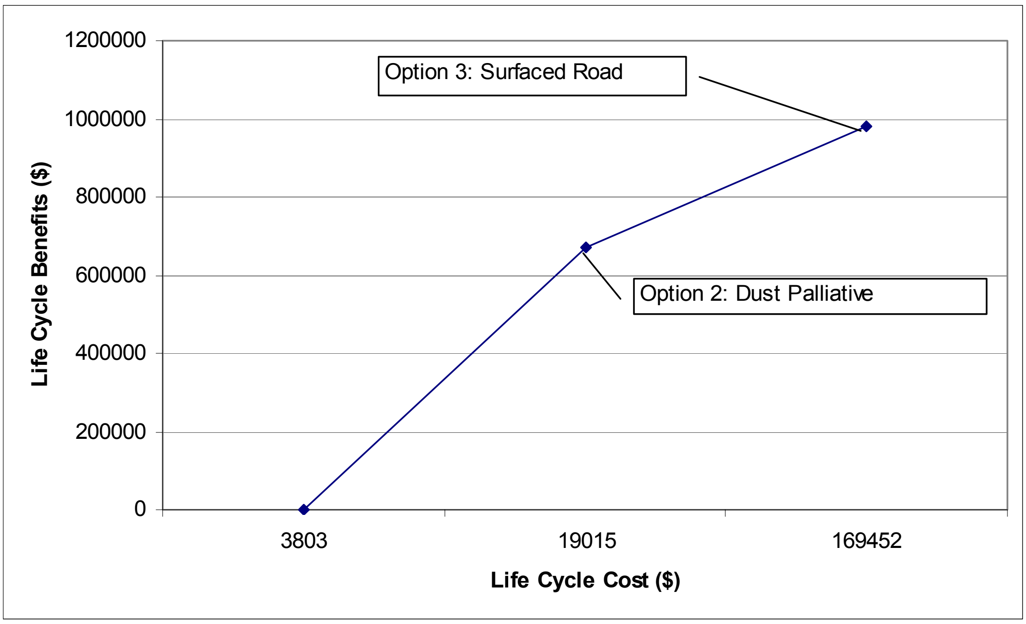


Figure 5.7: Life Cycle Benefit and Cost Graph for Three Options

Both the two alternative surfacing options resulted in having a positive incremental benefit compared with the base strategy (keep the existing unsurfaced road). Any of these two options would therefore be an economic surfacing option. The final selection between the dust palliative and surfacing option would depend on the availability of funding for the capital investment and the annual maintenance cost associated with each option.

6. Summary and Recommendations

In the course of the last century a significant road length was covered with dust-free, smooth all-weather surfacing. Despite the extensive road construction programmes, a substantial proportion of roads remained unsealed in the developing and emerging economies. Though several publications summarise the best technologies to maintain unsealed roads, few of them are fully applicable for developing countries. One over-ruling issue is the different interpretation of economic efficiency. In developed countries labour is one of the most expensive items, while in developing countries labour intensive technologies are not only the cheapest, but carry additional social benefits. Consequently, different technologies are suitable for the differing socio-economic conditions.

As economies develop, the need arises to pave previously unsealed roads. The most economical transition point between unsealed and paved roads depends on many conditions. The purpose of this document is to provide guidance for decision makers, engineers and administrators on the critical factors defining the optimum transition point.

The report offers detailed discussion on the following:

- Summary of current international experience based on literature survey
- Summary of current international experience based on a questionnaire
- Development of a decision framework

A review of the current international practice is presented including examples and a brief summary of experience. In the last decade the specific needs of developing economies were acknowledged, the localised technologies emerged alongside the traditional transfer of technology type approach. Emphasis shifted towards employing technologies that contribute to the development of the local economy. The principles of sustainable development and preservation of natural resources became a significant aspect in the selection of technologies.

A questionnaire was developed and distributed among a wide circle of practitioners around the world. The Internet allowed quick and broad distribution of the questionnaires. The responses were as diverse as the respondents and their circumstances. The wide range of approaches confirmed the need for some guidelines assisting the decision makers when to upgrade roads from unsealed to sealed surfacing.

The last part of the report offers a decision framework. The framework was developed to offer firm guidelines and to remain flexible enough to be applicable for most circumstances. The framework offers both a methodology that may be adapted by the user to specific conditions or can be used as is with the suggested parameters.

The decision framework comprises of the following steps:

1. Evaluate need for upgrading on the basis of local environmental and geographic conditions; this step also has allowance of overriding political or other aspects. A "go/no-go "decision can be made after this step.
2. Select suitable technologies from the presented list. Two lists are presented; a generic one that illustrates the methodology and major criteria and a detailed list that may be used directly or as an example for local adaptation. As a result of this step, the user will have a short list of options.
3. Economic and Financial analysis techniques are suggested to rank the technically feasible options developed during step 2. The user can choose between economic and financial analysis or may use both, depending on local circumstances. The methodology and suggested parameters are provided in the document.

The report provides a structured framework that should assist decision makers to evaluate proposed upgrades and to select the most appropriate technology.

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Appendix A: Evaluating the Need for Upgrading

Physical Factors			
TOPOGRAPHY	**GRADE**	**SCORE**	
Flat or Undulating area	<4%	0	
Undulating to Hilly area	4 - 8%	2	
Hilly to Mountainous	8-14%	4	
Mountainous with steep sections	>14%	5	
FACTOR SCORE			
COMBINATION OF CLIMATE AND SOIL CONDITIONS			
Soils mostly suitable for prevailing weather (e.g. most soils are suitable in arid environment, except sand) and traffic		0	
Soils suitable for prevailing weather only if treated (e.g. stabilised)		3	
Soils predominantly are unsuitable as road surfacing for given climate (e.g. clayey material in wet, or sand in arid climate)		5	
FACTOR SCORE			
Socio Economic Factors			
NON-MOTORISED TRAFFIC DEMAND FOR SURFACING			
Animal or non-motorised traffic with low volume/demand for sealed surface		1	
Non-motorised traffic with medium volume/demand for sealed surface		3	
Non-motorised traffic with high volume/demand for sealed surface		5	
FACTOR SCORE			
MOTORISED TRAFFIC VOLUME (annual average daily traffic in both directions)			
< 50		1	
50 – 200		3	
>200		5	
FACTOR SCORE			
POTENTIAL IMPACT OF DUST FORMING			
Slight – minor agricultural area with scarce population		1	
Medium – agricultural area, low – medium density population		3	
Severe - major agricultural area, densely populated		5	
FACTOR SCORE			
COMMUNITY IMPACT			
Slight – after sealing the road, trade opportunities will not change significantly or project will not create any local employment opportunities		1	
Medium – Some improvement is anticipated, some employment opportunities are created		3	
Severe – Significant improvement is anticipated or extensive employment opportunities are created		5	
FACTOR SCORE			
WILL TRAFFIC INCREASE AFTER SEALING			
Unlikely		1	
Some		3	
Likely		5	
FACTOR SCORE			
AVAILABILITY OF QUALITY MATERIAL			
Available and short hauling distance		0	
Available but hauling distance is more than 10km		3	
Suitable material is scarce or depleted		5	
FACTOR SCORE			
GRAND TOTAL			

Notes

Topography
The grade of a road has a profound impact on the economic use and maintenance of a road. Steep grades have increasing surface drainage requirements, as the damage caused by the flow of water escalates with increasing grade. At the same time, vehicles need better purchase on the ground to maintain safe passage. The steeper the road, the more justified it is to provide an all weather sealed surface. Grade may vary along the road. Therefore a selective, differential or spot improvement approach may be justifiable along a particular route.

Climate and Soil conditions
The combination of climate and soil together determine the extent of accessibility periods without a sealed surface. The same traffic volume may require a fully sealed surface under certain environmental conditions, while under other conditions an unsealed surface might be satisfactory.

Non-Motorised Traffic Demand for Surfacing

From a socio-economic viewpoint, non-motorised traffic demand can have significant influence on the selection of the appropriate surface type for roads. Traditional engineering economic approaches often neglected non-motorised traffic since it is difficult to calculate an equivalent "road user" cost for non-motorised traffic. The composition of the traffic also plays a major part of the decision process. For example, if the traffic predominantly consists of animal transport a rougher surface would be suffice compared to say draw card or push bike type vehicles.

Motorised Traffic Volume
Motorised traffic normally has higher requirements from the surface to ensure adequate friction and to keep user costs at reasonably low level. The safety and operating requirements are reflected in the scores for traffic volume.

Dust effects
Dust is a major health and safety hazard with detrimental impact on local agriculture. The scoring supports any improvement that can reduce the generation of dust:

Community impact
Road improvements generally assist the development of trade, agriculture and industry. The degree of impact is of course related to the density of population and several other factors. The impact of road improvement is scored according to the anticipated level of development in the community.

Material Availability

Material availability is often one of the overriding factors in determining suitable surfacing for unsealed roads. For example, much of Cambodia and Botswana is predominantly sand and assumptions that suitable material is available may not be valid. In these cases justification to seal roads with traffic volumes as low as 50 vehicles per day has been documented.

Appendix B: Detailed Assessment of Surface Options

Table B-1 Engineering assessment

No	Road Surface Improvement Options	Production Equipment requirement	Laying equipment required	Imported material required	Skill level	Traffic Capacity	Gradient Suitability	Local Employment opportunity	Flood resistance	Dust suppression	Use of finite resources	Maint. Liability
1	Slurry Bound Macadam Roadbase	high	medium	yes	medium	high	steep	high	medium	high	low	medium
2	Bituminous Premix Macadam Surface	high	high	yes	medium	high	steep	high	medium	high	low	high
3	Penetration Macadam Surface	high	high	yes	medium	high	steep	high	medium	high	low	medium
4	Asphalt	high	high	yes	high	high	undulating	low	low	high	medium	high
5	Bituminous/Tar Sand Seal Surface	medium	medium	yes	high	high	undulating	low	low	high	medium	medium
6	Ottaseal Surface	medium	medium	yes	high	high	undulating	low	low	high	medium	medium
7	Bitumen/Tar Surface Dressing Surface	medium	medium	yes	high	high	undulating	low	low	high	medium	high
8	Bitumen Slurry Seal Surface (and "Cape" Seals)	medium	medium	yes	high	high	steep	low	medium	high	medium	medium
9	Clay Brick Surface	low/medium	high	yes	medium	medium	steep	high	medium	high	low	low
10	Concrete Block Surface	low/medium	medium	yes	medium	high	steep	high	medium	high	low	medium
11	Plain concrete	medium	low/medium	yes	medium	medium	steep	high	high	high	medium	medium
12	Bamboo Reinforced Concrete Surface	medium	medium	yes	medium	high	steep	medium	high	high	medium	medium
13	Steel Reinforced Concrete Surface	medium	medium	yes	medium	medium	steep	medium	high	high	medium	high
14	Chemical or Emulsion Stabilized Roadbase	medium	medium	yes	medium	high	steep	low	medium	high	low	medium
15	Natural Gravel Surface	medium/low	low	no	low	medium	undulating	medium	nil	low	high	low
16	Lime Stabilization of Existing Surface	medium	low/medium	yes	low	medium	undulating	medium	low	medium	medium	low
17	Dragging Road Surface	low	low	no	low	low	flat	low	nil	nil	high	low
18	Light Grading/Reshaping of Surface	low	low	no	low	low	flat	low	nil	nil	high	low
19	Dust proofing	medium	medium	yes	low	medium	undulating	low	nil	high	medium	low
20	Improvement using Recycled Materials	medium	medium	no	medium	high	steep	medium	medium	high	low	low
21	Stone Chippings Surface	low	low/medium	no	low	medium	undulating	high	low	medium	medium	medium
22	Hand Packed Stone Surface	low/medium	low/medium	no	low	high	undulating	high	high	high	medium	low

No	Road Surface Improvement Options	Production Equipment requirement	Laying equipment required	Imported material required	Skill level	Traffic Capacity	Gradient Suitability	Local Employment opportunity	Flood resistance	Dust suppression	Use of finite resources	Maint. Liability
23	Water Bound Macadam Roadbase	low/medium	medium	no	medium	high	steep	high	medium	high	low	low
24	Dry Bound Macadam Roadbase	low/medium	medium	no	medium	high	steep	high	medium	high	low	low
25	Crushed Stone Roadbase	medium	medium	no	medium	high	steep		medium	high	low	high
26	Mechanically Stabilised Roadbase	medium	medium	no	medium	high	undulating	low	medium	high	low	high
27	Dressed Stone Surface	low	low/medium	no	medium	medium	steep	high	medium	high	low	medium
28	Stone Sett Surface (Pavé)	low	medium	yes	medium	medium	steep	high	medium	high	low	medium

Table B-2 Performance of Surface Options

No	Road Surface Improvement Options	Corrugation	Pothole	Erosion	Ravelling	Dustiness	Structural	Rutting	Typical life	Roughness	Comments
1	Slurry Bound Macadam Roadbase	low	medium	low	low	low	medium	low	7-10 yr	medium	labour intensive, quality crushed rock required, compaction is essential
2	Bituminous Premix Macadam Surface	low	medium	low	low	low	medium	medium	10-15 yr	low	labour intensive, quality crushed rock, bitumen and equipment required
3	Penetration Macadam Surface	low	medium	low	low	low	medium	low	10-15 yr	low	labour intensive, quality crushed rock, bitumen required
4	Asphalt	low	medium	low	low	low	medium	medium	10-15 yr	low	technological discipline, equipment and quality materials needed. Length of supply chain increases costs
5	Bituminous/Tar Sand Seal Surface	low	medium	low	low	low	medium	medium	7-12 yrs	medium	Bitumen supply required
6	Ottaseal Surface	low	medium	low	low	low	medium	medium	7-12 yrs	medium	Bitumen supply required
7	Bitumen/Tar Surface Dressing Surface	low	medium	low	low	low	medium	medium	7-12 yrs	medium	Bitumen supply required
8	Bitumen Slurry Seal Surface (and "Cape" Seals)	low	medium	low	low	low	medium	medium	10-15 yr	medium	Bitumen and crushed rock supply required - slurry equipment needs skills
9	Clay Brick Surface	low	low	low	low	low	high	low	10 - 20 yrs	medium	locally manufacturing and supply
10	Concrete Block Surface	low	low	low	low	low	high	low	10 - 15 yrs	medium	easy to repair
11	Plain concrete	low	low	low	low	low	high	low	10 - 20 yrs	medium	maintenance intensive
12	Bamboo Reinforced Concrete Surface	low	low	low	low	low	high	low	10 - 20 yrs	low	difficult to repair
13	Steel Reinforced Concrete Surface	low	low	low	low	low	high	low	20 - 30 yrs	low	difficult to repair
14	Chemical or Emulsion Stabilized Roadbase	medium	medium	medium	low	low	high	medium	5-10 yrs	medium	environmental concerns, performance is variable
15	Natural Gravel Surface	high	high	high	high	high	high	high	3-7 yrs	high	very sensitive to weather
16	Lime Stabilization of Existing Surface	low	medium	medium	med	low	high	medium	7-12 yrs	medium	mainly for clay materials
17	Dragging Road Surface	high	high	high	high	high	high	high	1-2 yrs	high	short term solution - maintenance intensive
18	Light Grading/Reshaping of Surface	high	high	high	high	high	high	high	1-3 yrs	high	short term solution - maintenance intensive
19	Dust proofing	high	high	high	high	medium	high	high	1-3 yrs	high	short term solution - maintenance intensive
20	Improvement using Recycled Materials	medium	medium	medium	medium	medium	medium	medium	7-12 yrs	medium	environmental concerns, performance is variable
21	Stone Chippings Surface	medium	medium	low	medium	medium	high	medium	10-15 yr	medium	manual labour intensive
22	Hand Packed Stone Surface	low	medium	low	low	low	medium	low	10-15 yr	medium	manual labour intensive
23	Water Bound Macadam Roadbase	low	medium	low	low	low	low	low	10-15 yr	low	reliable and proven method - difficult to repair
24	Dry Bound Macadam Roadbase	low	medium	low	medium	medium	medium	medium	7-12 yrs	medium	reliable and proven method - difficult to repair
25	Crushed Stone Roadbase	low	medium	low	medium	high	low	medium	7-12 yrs	medium	reliable and proven method - difficult to repair
26	Mechanically Stabilised	medium	high	medium	medium	medium	medium	medium	7-12 yrs	medium	control of compaction is essential

No	Road Surface Improvement Options	Corrugation	Pothole	Erosion	Ravelling	Dustiness	Structural	Rutting	Typical life	Roughness	Comments
	Roadbase										
27	Dressed Stone Surface	low	medium	low	low	medium	medium	low	10-15 yr	medium	labour intensive but with proven record - easy to maintain
28	Stone Sett Surface (Pavé)	low	medium	low	low	low	low	low	10-15 yr	medium	labour intensive but with proven record - easy to maintain

Table B-3 Classification of Surfacing Used in Table 5.4 and Table Above (based on Gourley et al, 2002)

Road Surface Improvement Options	Description	Material	Subgroup
Dragging Road Surface	Smoothing out minor defects on an earth or gravel road surface and redistributing loose material on the surface, using tyre or blade drag.	Natural	untreated
Light Grading/Reshaping of Surface	Minor reshaping of an earth or gravel surface to restore correct camber using labour or light/heavy grading equipment.	Natural	untreated
Natural Gravel Surface	A layer of compacted natural gravel wearing course (typically 15 – 20cm thick)	Gravel	untreated
Lime Stabilization of Existing Surface	Addition of and mixing of quicklime or hydrated lime to a soil or surface material, watering and compaction to increase its strength and reduce its susceptibility to the weakening effect of increasing moisture content. This is achieved by chemical reaction of the lime with the clay particles. Mixing and compaction by light or heavy equipment.	Gravel	Surface treatment
Stone Chippings Surface	A layer of single sized (typically 20mm) crushed stone chippings.	Stone	Crushed
Hand Packed Stone Surface	A layer (typically 20 – 30cm thick) of large broken stone pieces tightly packed and wedged in place with stone chips rammed in by hand into joints, with remaining voids filled with sand. The Hand Packed Stone is normally bedded on a thin layer of sand/gravel.	Stone	Crushed
Dressed Stone Surface	A layer (typically 15 – 20cm thick) of stone blocks cut (dressed) to a cubic shape by hand, laid by hand. Joints mortared/sealed or tightly packed and wedged with stone chips rammed into place with remaining voids filled with sand. The Dressed Stone is normally bedded on a thin layer of sand/gravel.	Stone	dressed/block
Stone Sett Surface (Pavé)	As dressed stone, however stone blocks are smaller; typically about 10cm x 10cm x 10cm with mortared joints.	Stone	dressed/block
Concrete Block Surface	A layer of concrete blocks (typically each 10cm x 20cm and 7 – 10cm thick) laid by hand on a thin (3 – 5cm) sand bed with joints also filled with sand and lightly compacted.	Concrete	dressed/block
Clay Brick Surface	A layer of high quality clay bricks (typically each 10cm x 20cm and 7 – 10cm thick) laid by hand on a thin sand bed with joints also filled with sand and lightly compacted, or bedded & jointed with cement mortar.	Clay Brick	dressed/block
Plain concrete	Plain mass concrete	Concrete	
Bamboo Reinforced Concrete Surface	Jointed slabs of structural quality concrete reinforced with a split bamboo rod grid. Joints with steel weight transfer dowels and bitumen seal.	Concrete	
Steel Reinforced Concrete Surface	Jointed slabs of structural quality concrete reinforced with a mild steel rod grid. Joints with steel weight transfer dowels and bitumen seal.	Concrete	
Bituminous/Tar Sand Seal Surface	A seal consisting of a hand or machine applied film of bitumen (straight run, cutback or emulsion) or road tar followed by the application of excess angular sand or fine crushed stone, lightly rolled into the bitumen/tar.	Bituminous	Seal
Ottaseal Surface	A layer consisting of a hand or machine applied film of relatively soft bitumen (usually straight run or cutback) followed by the application of graded natural gravel or crushed stone aggregate (typically 16mm downwards), rolled into the bitumen using heavy pneumatic tyred rollers.	Bituminous	Seal

Road Surface Improvement Options	Description	Material	Subgroup
Bitumen/Tar Surface Dressing Surface	A seal consisting of a hand or machine applied film of bitumen (straight run, cutback or emulsion) or road tar followed by the application of a single layer of single sized (6 – 20mm) stone chippings, lightly rolled into the bitumen/tar.	Bituminous	Seal
Bitumen Slurry Seal Surface (and "Cape" Seals)	A seal consisting of fine graded aggregates (typically 10mm downwards), water, bitumen emulsion, cement, and sometimes an additive, mixed in a concrete mixer or other machine and spread on the road surface by hand or machine. Cape seals are combinations of Surface Dressing and Slurry Seal.	Bituminous	Seal
Bituminous Premix Macadam Surface	Graded crushed stone material (typically 28mm downwards) usually derived from fresh sound quarried rock, boulders or granular material and mixed with a bituminous binder (straight run, cutback or emulsion) and laid and compacted. Material may be hand or machine mixed and laid. Compaction by light or heavy equipment.	Bituminous	Mix
Penetration Macadam Surface	Two or three layers of single size crushed stone (of decreasing nominal aggregate size, e.g. 63 mm downwards) each compacted and with bitumen (straight run, cutback or emulsion) or road tar sprayed between each stone application.	Bituminous	Mix
Asphalt	Hot or cold asphalt mix	Bituminous	Mix
Water Bound Macadam Roadbase	A layer of nominal single sized (typically up to 50mm) crushed stone compacted and fully blinded with well graded fine aggregate which is watered into the voids and compacted to produce a dense stable material. Layer thickness up to twice the nominal stone size. Material may be hand or machine crushed and laid.	Stone	Crushed
Dry Bound Macadam Roadbase	A layer of nominal single sized (typically up to 50mm) crushed stone compacted and fully blinded with angular sand or fine crushed stone material which is then vibro-compacted to produce a dense stable material. Layer thickness up to twice the nominal stone size. Material may be hand or machine crushed and laid. Suitable in areas short of water.	Stone	Crushed
Slurry Bound Macadam Roadbase	*A layer (about 7cm thick) of single size aggregate (typically 50mm) blinded with smaller aggregate (typically 25mm), plate compacted and grouted with bitumen emulsion slurry before final compaction.*	Bituminous	Crushed
Crushed Stone Roadbase	A layer (usually up to 20cm thick) of graded crushed stone material (typically 50mm downwards) usually derived from fresh sound quarried rock, boulders or granular material. The angular material derives its strength primarily from mechanical interlock. Material may be hand or machine crushed.	Stone	Crushed
Mechanically Stabilised Roadbase	Addition and mixing of granular material such as crushed stone or sand to a material to increase its strength and achieve the properties required of a roadbase.	Stone	Crushed
Chemical or Emulsion Stabilized Roadbase	Addition and mixing of a stabilizer such as lime, cement, or ion exchange chemicals, to a material to increase its strength and achieve the properties required of a roadbase. Mixing and compaction by light or heavy equipment.	Stone	Stabilised
Improvement using Recycled Materials	Use of recycled road pavement materials, brick kiln waste, broken brick, demolition materials, industrial slags, etc.	Other	Stabilised

Appendix C: Additional Information for Economic Analysis

Present value

The following equation can be used to find the Present Value of a Cash Flow Stream.

$$PV = \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t}$$

where

PV = the Present Value of the Cash Flow Stream,
CFt = the cash flow which occurs at the end of year t,
r = the discount rate,
t = the year, which ranges from zero to n, and
n = the last year in which a cash flow occurs.

Net Present Value

The NPV is calculated as the present value of the project's cash inflows minus the present value of the project's cash outflows. This relationship is expressed by the following formula:

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t} = CF_0 + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + ... + \frac{CF_T}{(1+r)^T}$$

where

CF_t = the cash flow at time t and
r = the cost of capital or discount rate.

Assumedium and suggested input parameters

Discount rate 8 – 12%

Construction Costs

Construction costs need to be estimated using local labour and material costs

Surfacing lives for life cycle cost calculation:
(after SABITA M10, 1992)

Surfacing	traffic life range (years)
Asphalt	10-14
Double Seal, Cape Seal	6 – 8
Single seal	4-6
Dust Palliative	1- 3
Re-gravel	3-7
Concrete	15-25

Road user costs

Typical vehicle operating costs (1998/99 prices) for flat terrain in remote areas
(Source: ARRB Transport Research Ltd VOC Model, 1998/99)

Parameter		Value ($)	
		Typical vehicle operating costs, cents/veh km (fair surface condition and flat terrain)	
		Light vehicle	Heavy vehicle*
Earth Formation	60 km/h	45.5	139.8
	80 km/h	47.0	144.3
Gravel Surface	70 km/h	29.0	88.7
	90 km/h	30.9	94.7
Sealed Surface	80 km/h	21.5	61.1
	100 km/h	23.2	69.8

NOTE: * Lower operating costs to earlier values due mainly to reduced maintenance costs and loading conditions

Table 2: Car Speeds and Unit Road User Costs per Season

Road Quality Level	Dry season				Wet Season			
	Car Speed (km/hr)	Fleet VOC ($/v-km)	Fleet VOT ($/v-km)	Fleet RUC ($/v-km)	Car Speed (km/hr)	Fleet VOC ($/v-km)	Fleet VOT ($/v-km)	Fleet RUC ($/v-km)
Unpaved Very Poor	28	0.515	0.109	0.624	25	0.560	0.124	0.684
Unpaved Poor	37	0.439	0.085	0.523	25	0.560	0.124	0.684
Unpaved Fair	48	0.375	0.065	0.441	28	0.515	0.109	0.624
Unpaved Good	61	0.330	0.051	0.381	61	0.330	0.051	0.381
Unpaved Very Good	78	0.288	0.040	0.328	78	0.288	0.040	0.328
Paved Very Poor	52	0.360	0.060	0.420	52	0.360	0.060	0.420
Paved Poor	72	0.301	0.043	0.345	72	0.301	0.043	0.345
Paved Fair	84	0.247	0.037	0.284	84	0.247	0.037	0.284
Paved Good	85	0.234	0.037	0.271	85	0.234	0.037	0.271
Paved Very Good	85	0.230	0.037	0.267	85	0.230	0.037	0.267

Source: (Archondo-Callao, 2004)

Typical Capital and Maintenance Costs

Maintenance costs are highly dependent on local conditions including the environment. The flowing example shows the key items to include based on a high-wage, low-cost of capital environment:

YEAR	1	2	3	4	5	6	TOTALS
GRADING							
Equipment	270	280	290	300	310	320	1,770
Labor	90	100	110	120	130	140	690
REGRAVEL							
Materials	–	–	4,000	–	–	–	4,000
Equipment	–	–	2,500	–	–	–	2,500
Labor	–	–	2,300	–	–	–	2,300
STABILIZATION/DUST CONTROL							
Materials	800	900	1,200	920	950	975	5,745
Equipment	30	35	70	40	50	60	285
Labor	100	110	150	125	140	150	775
Totals	1,290	1,425	10,620	1,505	1,580	1,645	$18,065

(Skorseth, K., Selim, A. A; U.S. Department Of Transport FHA Gravel Roads Maintenance and Design Manual South Dakota Local Transportation Assistance Program (November 2000)

Table 4 Project Alternatives

Project Alternative	Alternative Description	Investment Cost (000$/km)	Maintenance Cost ($/km-yr)	Average Roughness (IRI)
Without Project-Alternative	Keep Unpaved Very Poor	0	500	22.7
Project-Alternative 1	Improve to Unpaved Poor	5	1,000	19.0
Project-Alternative 2	Improve to Unpaved Fair	10	1,500	15.2
Project-Alternative 3	Improve to Unpaved Good	30	3,000	10.0
Project-Alternative 4	Improve to Unpaved Very Good	95	4,000	7.0

Source: (Archondo-Callao, 2004)

Appendix D Surfacing Alternative Methods - Questionnaire

Objectives Background

The primary objective of the questionnaire was to ascertain any common practice in the surfacing alternative decision process used around the world. The questionnaire sought further input, clarification and innovation on issues from both geographically and socio-economically diverse groups of candidates. The questionnaire was also valuable for obtaining further information and to confirm (and/or challenge) previous findings. The results of the questionnaires also assisted in the formation of the recommended decision framework.

Methodology

The initial development of the questionnaire centred on key issues identified during the literature review, initial investigations into field trails, and previous correspondence relevant to the maintenance of unsealed roads. The questionnaire incorporated a number of external review / alteration cycles, both by the World Bank and by recognised industry specialists. It covered the following main topic areas:

- General characteristics of the network;
- Surfacing of unsealed roads and maintenance options;
- Factors influencing the selection of surface options for unsealed roads;
- Availability of material, labour, and technology;
- Funding and maintenance management; and,
- Information on unsealed trials.

One of the key issues faced when compiling the questionnaire was to keep it short, whilst at the same time incorporating the diverse range of issues that needed to be allowed for in the final decision framework. The final questionnaire was ultimately a compromise between ‘pure’ surface maintenance factors requiring consideration, and those tangible/intangibles that ultimately form part of the required decision process.

The questionnaire was implemented through a web-based system (provided by Zoomerang) for distribution to the selected candidates. The use of the web-based system was to allow for quick and easy dissemination of the questionnaire to the candidates, along with the ability to quickly collate and review the results.

The candidates were sent an email that contained a brief introduction about the project, the purpose of the questionnaire, and a link to the introduction page of the questionnaire. Invitation emails were sent out from both the World Bank and MWH NZ. Candidates were asked to respond by the 23rd November 2004, allowing approximately 2 weeks for them to read and follow the supplied link in the email.

After the closing date had passed the results were collated and analysed, the results of which are discussed below.

Results

The response (total of 22) on the questionnaire was relatively poor to the extent that statistical analysis on the answers would be meaningless. However, through personal contacts it was ensured that recognised specialists around the world responded to the questionnaire. First, the official reviewers of the project had to respond. In addition to this, the unsealed road working group at the 6th International Conference on Managing Pavements were requested to complete the questionnaire. It can therefore be safely assumed that the key specialists around the world had an input and relevant conclusions can be drawn from the answers. A good spread of respondents mainly from the southern hemisphere and Asia had also responded.

Network Characteristics

The majority of the respondents indicated that the bulk of their unsealed roads are constructed and maintained using materials sourced from borrow pits within 10km of the actual roads. In some cases longer hauling distances were indicated. The use of crushed rock and mixing of different material types together are common practices around the world. Dust palliatives are used on a range of networks but to a limited extent on each network. For example all the respondents indicated that the total length of the network treated with dust palliatives would normally be less than 10% of the total network.

The climate and moisture regime varied significantly and ranged from tropical to cool and arid to per-humid respectively. The majority of the networks sampled fell in the "rolling" topographical classification.

The following comments were made regarding the relevance of the network-characteristics and the surfacing decisions:

- (India) - High rainfall results in surface drainage to be important. In such cases an impermeable surface is used (e.g. micro silica modified overlay);
- In South Africa (Western Cape) a different approach is adopted for urban and rural networks. For example:
    - Urban (water carried on surface) - no single or stone seals (prefer stone and sand or stone and slurry). It should be noted that these roads are often used by non-motorised travel.
    - Rural with high maintenance capability - sand or stone seals allowed
- (New Zealand) - Higher plasticity gravels (clayey material) are used for wearing courses in drier regions, while lower plasticity gravels are used in wetter areas. Grading is only undertaken during periods of optimum moisture condition.

Surfacing and Maintenance Options for Unsealed Roads

One of the questions was to quantify the factors that contribute towards failure of the unsealed road network. The aim was to gain a better understanding of the drivers behind unsealed road maintenance and surfacing decisions. Figure D.7.1 depicts the average distribution of the responses. It shows that the predominant factors for unsealed road failure are environmental and traffic loading. Poor construction and drainage failure were also indicated as factors in the performance of unsealed roads but were not rated as high as the traffic and environmental factors.

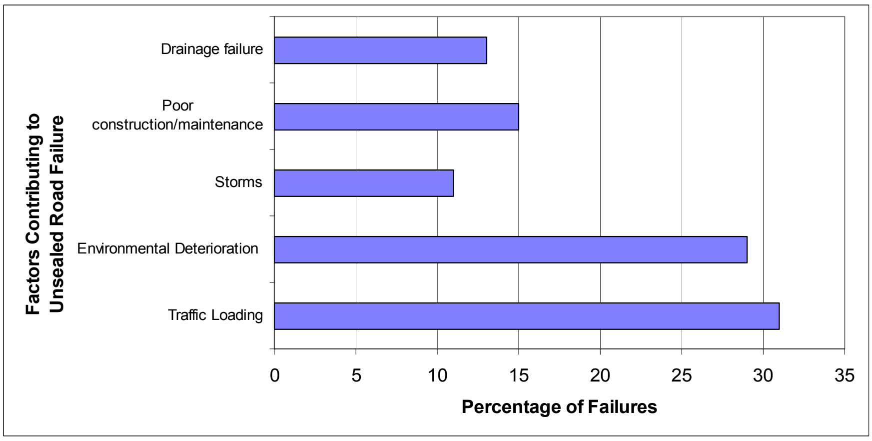

Figure D.7.1: Factors Indicated for Unsealed Roads Failures

All the respondents indicated the importance of drainage on the behaviour of the unsealed roads. In spite of this, only one authority indicated that they had an official drainage design guide.

The deciding factors used to determine specific surfacing options are summarised in Table D.7.1

Table D.7.1: Deciding Factors to Determine Specific Surface Types

Factor	Relevant Surface Type	Comment
Traffic Volume	Upgrading to sealed road	Due to economic considerations
Dust	Dust Palliative or clay bound wearing course	Due to residential and farming considerations
Stressed areas / steep gradients	Upgrading to surfaced road	Often at turning areas and bridge abutments
Scarce Material	Upgrading to surfaced road	
Skid problems	Upgrading to surfaced road or re-alignment	
Social considerations	Through settlements slurry seals are used where children play	

Some decision processes also include:

- Economic evaluations, both benefit/cost (B/C) and Net present Value (NPV) analyses;
- Environmental considerations; and,
- User needs and expectations.

Management of Unsealed Roads

All respondents indicated that the bulk of their unsealed road funding is secured through central and/or local government (rates). Private funding comes from forestry or private tourist enterprises only in isolated cases. As expected, the maintenance funds are determined by either historical quantities or operational planning in the majority of cases. Only two respondents indicated that a computerised system is used for determining the funding level.

Most respondents indicated that the maintenance of unsealed roads is undertaken by private contractors. There were two areas that used performance specified maintenance contracts (PSMC), with the majority of authorities doing the maintenance planning internally or by consultants, and then appointing a contractor according to a fixed rate method.

All of the respondents indicated the use of some systems to assist in the management of unsealed roads. The uptake of the various systems is summarised in Figure D.7.2.

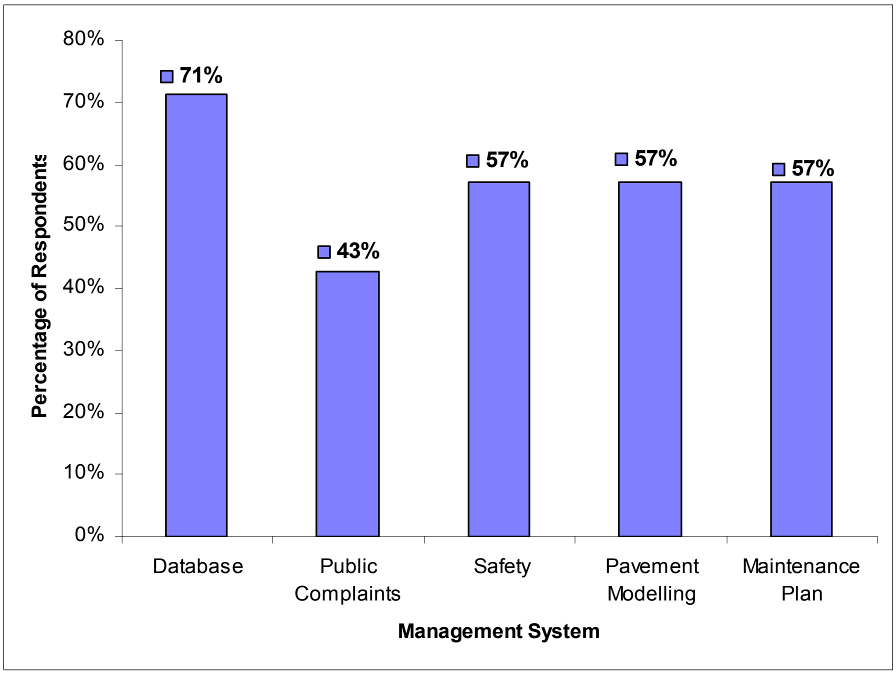

Figure D.7.2: Systems Used for Managing Unsealed Roads

Figure D.7.2 shows that most respondents are using a database and an equal amount are using safety and modelling systems. Almost 45 percent of respondents were also using a public complaint system to determine maintenance needs.

Discussion

Despite the low response to the questionnaire, useful input was gathered regarding the circumstances and rationale for making decisions on surfacing of unsealed roads. A good representation of countries responded to the questionnaire, which gave a collection of practices used for unsealed roads based on varying conditions and climates.

There were a number of common considerations between the different countries, especially in relation to deciding upon the appropriate surface options. However, the emphasis on these factors differed somewhat. For example, some countries had a high priority on providing access while others focused more on safety. It was also encouraging to note that there was a strong focus on both socio and environmental considerations. The results from the questionnaires were used in Chapter 5 to develop the decision framework.