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Surfacing Alternatives for Unsealed Rural Roads

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Despite extensive road construction programs over the last century, a substantial proportion of roads remained unsealed especially in developing and emerging economies. As these economies develop, the demand arises to seal previously unsealed roads. The most economical transition point between unsealed and sealed roads depends on many conditions that need to be evaluated.

The purpose of this Note is to provide guidance for decision makers, engineers and administrators on selecting the most appropriate surface for unsealed road given the prevailing conditions. It is based on the report "Surfacing Alternatives for Unsealed Roads" (Henning, et al.2005).

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1 Types of Unsealed Roads

Unsealed roads are defined as all roads without a permanent waterproof surface. These include engineered and un-engineered roads. Under this definition, four types of unsealed roads can be distinguished:

- **Unformed Roads or Earth Roads:** have no drainage, cross fall, added granular material or other features that would ensure all-weather access.
- **Formed Roads:** have a reasonably well defined cross section, including drainage. They usually consist of locally available earth material with no added surfacing material.
- **Graveled Roads:** are built and designed to certain engineering principles, including the supply, where warranted, of gravel wearing surface. Construction of these roads also involves a defined cross section, drainage and structures (bridges, culverts).
- **Sealed Roads:** these are all-weather dust-free surfaces. Sealing is done with a wide range of technologies from bitumen seal to thin (not load bearing) asphalt surfacing.

2 Key Issues on Unsealed Roads Maintenance

The broad objective of maintenance activities on unsealed roads are to: (i) preserve the road in a condition close to its intended or as-constructed state and, (ii) to ensure an acceptable level of service through control of the various deterioration modes. Maintenance activities differ depending on the type of unsealed road. This is mainly due to the characteristics of each road type and the traffic. For example, unformed roads are most common when the dominating traffic is animal driven, low speed or light motorized. On the other hand, sealed roads typically allow vehicular speed in excess of 60 km/h and are often primarily built for motorized vehicle traffic.

Knowledge on the failure modes of unsealed roads contributes to the selection of the most appropriate treatment and maintenance activities. Failures can be classified as structural and surface defects.

Structural defects are due to the failure of the sub-grade or pavement layers. They are mainly related to material, pavement depth, geometry and/or drainage deficiencies. Structural defects typically appear as soft or wet patches, larger depressions or loss of pavement.

Surface defects mainly affect ride quality and appear in various failure types, such as: roughness, corrugations, potholes, rutting, scouring/erosion, raveling, loss of surface material, dustiness, stoniness and slippery surface.

Box 1
How can a Good Surface Performance be Achieved in Unsealed Roads?

- **Maintaining the Drainage System**: This is considered the most important maintenance function and should be performed as a routine activity to minimize deterioration of the road surface/structure. The drainage system needs to be regularly cleaned of silt, material accumulations and debris.
- **Selecting Quality Materials:** This includes the appropriate material type and other characteristics such as grading. Research in Australia and South Africa have indicated that ensuring appropriate grading distribution enhances the performance of unsealed roads (Paige-Green, 1989 and ARRB, 2000).
- **Grading/Reshaping**: Routine and periodic grading should be performed to ensure adequate ride quality and safety.
- **Ripping and Reworking Existing Layers**: Can also be considered as a severe case of grading. The operation entails scarifying the surface and adding and mixing new materials.
- **Regraveling**: 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.
- **Controlling Vegetation**: This considers control of grass, shrubs, bushes and trees as routine maintenance.

3 International Experiences

Long term performance studies are conducted to understand and quantify the behavior of pavements under operational conditions, including climate and traffic loading. Some outcomes include:

- Establishing deterioration models for local roads (Giummarra et al, 2004) by monitoring road roughness, gravel loss, loss of shape and loose stones; and,
- Monitoring the deterioration of the unsealed roads (MWH, 2001) as a function of: maintenance practices, site geometry, climate and rainfall, traffic volume and types and aggregate properties.

It must be noted that all long-term performance studies must consider 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.

A major study was recently conducted in Vietnam. The objective of the study was to complement the national standards with a full range of surfacing options. For these, alternative road surfaces were studied, which better use local resources in a sustainable way, minimizing whole-life-costs and supporting the government's poverty alleviation and road maintenance policies. Sixteen different pavement designs and compositions of alternative pavements at four different regions were evaluated (Petts. et al, 2005).

Some important issues identified in the study were:

- Unsealed stone macadam are highly effective in providing a sustainable surface/road-base, albeit with high surface erosion or roughness penalties.
- Other techniques utilizing natural stone, without bitumen or cement binder, could have superior performance to gravel, but with reasonable initial costs and lower maintenance liabilities.
- 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.
- Composite construction should be considered as a strategy in future rural road programs, using different surfacing options along a road link in response to differing environment impacts.

4 Surfacing Alternatives

Surfacing alternatives have evolved over a long period as new materials and technologies keep emerging.

4.1 Surface Types

A brief description of the main surface types, grouped according to their dominating constituent, is presented in Table 1. This is intended to assist in the selection of surfacing alternatives in terms of the surface type.

Table 1 Surface Types

SURFACING TYPE	DESCRIPTION
Natural Surfacing	Engineered earth roads or natural surfaces. Generally have poor geometry and drainage.
Gravel	Typically 150-250mm thick natural gravel or other imported layer that is worn down by traffic and the environment.
Dust Suppressants	Additionally to a good construction and a mechanical stabilization, dust can be controlled with chemical additives, such as: Wetting Agents, Salts/Chlorides, Natural Polymers, Wax Agents, etc. Dust suppression has environmental, health, safety and economic implications.
Stone	Crushed stone layers can be placed with machines or manually. The former require heavy equipment for compaction. The latter may be prepared without heavy compaction equipment.
Bricks	Usually prepared from high quality clay bricks. Pavements are very durable and can present a very tight, relatively smooth surface.
Concrete	Very durable, but mostly require minimum thickness for high volume roads. A special application is the concrete block pavement, with similar behavior and performance to brick and clay bricks.
Bituminous Surfaces	Classified in two groups: Seals (bitumen film and stone embedded) and Bituminous mixes (asphalt layers)
Other Surfaces	Recycled rubble, concrete or asphalt mix.

4.2 Surfacing and Alternative Treatments

Upgrading an unsealed road is a major jump in terms of road construction and maintenance. However, the benefits of upgrading come at a significant cost, as the construction and maintenance costs are significantly different from those of unsealed roads. The main benefits of sealing an unsealed road are:

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

Table 2 summarizes the surfacing and alternative treatments for sealed and unsealed roads.

Table 2 Surfacing Treatments

SURFACING GROUP	DESCRIPTION
Bituminous Macadam	Graded crushed stone material or single size aggregate blinded with smaller aggregate mixed with a bituminous binder or bitumen emulsion slurry
Asphalt	Hot or cold bituminous mix
Recycled Asphalt	Hot or cold recycled bituminous mix
Bituminous Seal Surface	Film of bitumen or road tar followed by angular sand, natural gravel or crushed stone, lightly rolled into the bitumen/tar.
Clay Blocks	High quality clay bricks on a thin sand bed.
Concrete Blocks	Concrete blocks laid on a thin sand bed.
Stone Blocks	Dressed stone or stone sett surface, cut and laid by hand
Plain Concrete	Plain mass of concrete
Reinforced Concrete	Steel reinforced mass of concrete
Stabilized Gravel	Road base mixed with stabilizers such as chemical additives or bitumen emulsions
Crushed Stone	A layer of graded crushed stone material derived from fresh sound quarried rock, boulders or granular material.
Stabilized Recycled Material	Use of recycled road pavement materials, brick waste, demolition materials, etc.
Natural Gravel	A layer of compacted natural gravel wearing course
Stabilized Natural Material	Stabilization of the soil or surface with natural materials like quicklime or hydrated lime.
Treated Natural Material	Surface treatment using natural material such as dust proofing
Natural Soil	Smoothing or shaping existing earth or gravel road surface

4.3 Factors to be considered when selecting surfacing alternatives

The main factors that need to be considered when deciding between surfacing types are presented below.

- Climate, Geography and Topography;
- Environmental and Socio-Economic Impact;
- Safety;
- Engineering Suitability;
- Durability of Surfacing;

- Failure Modes of Treatments;
- Political and Organizational Issues; and,
- Design Standards

It should be noted that any one, or the combination, of these factors may determine the surface type required.

5 Surfacing Alternative Decision Framework

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 agency through the decision process by explaining the factors that influences it.

It must be appreciated that the decision framework is not a simple choice between a surfaced and an unsealed road. In fact, it is a continuum and the choice depends on a range of factors. A holistic approach **must** be used considering all the factors influencing the project, such as: politically supported, socially acceptable, institutionally practical, technologically appropriate, economically viable, financially sound and environmentally sustainable (based on SATCC, 2003).

A three-step decision process was developed considering: demand assessment, selection of suitable technologies and an Economic/Financial analysis. Figure 1 graphically summarizes the 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 step is discussed below.

5.1 Step 1: Assess Demand for Sealed Surface

Under normal operational situations the network owner/authority will be aware of particular sections that are candidates for the upgrading to sealed roads. 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.

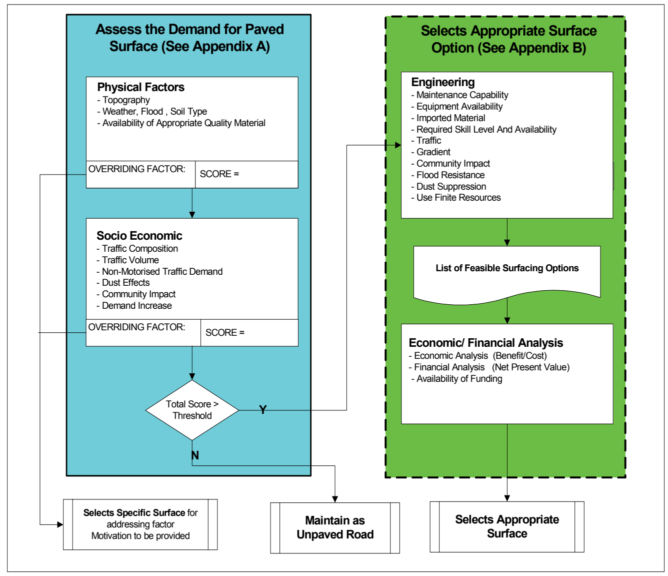

Figure 1 Graphical Presentation of Surface Alternative Analysis

A score sheet was developed to assist in evaluating the need to upgrade an unsealed road to a surfaced one. The score sheet assesses both the environmental and the socio-economic considerations affecting the decision to invest in the upgrading of the road. The main factors considered in the evaluation are: Topography, Climate/Soil Condition, Non-Motorized Traffic Demand, Motorized Traffic Volume, Potential Impact of Dust, Community Impact, Traffic Increase After Sealing and Availability of Quality Material. Each of these factors are subdivided in different impact levels, and for each level a score is assigned. A summary of the score sheet is presented in Table 3.

Total scores range from 5 to 30, where 30 represents a maximum need to upgrade an unsealed road and 5 a minimum need. The minimum score for a road to be considered for surfacing depends on the development of the country that is being assessed. Recommended minimum scores for different development levels are presented in Table 4.

Table 3 Score Sheet Summary	
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 (>14%)	5
CLIMATE & SOIL CONDITIONS	**SCORE**
Soils suitable for weather/traffic	0
Soils suitable for weather f treated	3
Soils predominantly unsuitable	5
Socio Economic Factors	
NMT DEMAND FOR SURFACING	**SCORE**
Animal or NMT with low volume	1
NMT with medium volume	3
NMT with high volume	5
MOTORIZED TRAFFIC VOLUME	**SCORE**
< 50	1
50 – 200	3
>200	5
IMPACT OF DUST FORMING	
Slight	1
Medium	3
Severe	5
COMMUNITY IMPACT	**SCORE**
Slight	1
Medium	3
Severe	5
TRAFFIC INCREASE AFTER SEALING	**SCORE**
Unlikely	1
Some	3
Likely	5
AVAILABILITY OF QUALITY MATERIAL	**SCORE**
Available and short hauling distance	0
Available but distance > 10km	3
Material is scarce or depleted	5

Note: NMT = Non Motorized Traffic

Table 4 Recommended Score System for Upgrading Unsealed Road to Surfaced Roads	
Unsealed Road Network	**Minimum Score**
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

5.2 Step 2: Identify Surfacing Options

The purpose of this second step is to identify surfacing alternatives and implement the concepts and principles to specific local conditions.

Currently available surfacing technologies were discussed and summarized in Table 2. A wider list of available technologies is presented in the complete report (Henning et al., 2005).

The main factors that need to be considered when deciding between surfacing types can be grouped into those relating to construction and maintenance; relating to the social and physical environment; and relating to the expected performance of the surface.

Factors relating to the construction and maintenance circumstances including:

- Design standards
- Production equipment requirement
- Laying equipment requirement
- Imported material requirement
- Skill level required
- Maintenance liability

Factors related to the physical and social environment:

- Traffic capacity
- Gradient severity
- Local employment creation opportunity
- Flood resistance
- Dust suppression
- Use of finite resources

Factors related to the expected performance of the surface:

- Corrugations
- Potholes
- Erosion
- Raveling
- Dustiness
- Structural Strength
- Rutting
- Roughness

5.3 Step 3: Financial and Economic Evaluation

Financial evaluation focuses on the cost of the project to the agency by comparing the construction and maintenance costs of the various options. Economic evaluation takes into account the total cost and benefits to the community. Table 5 suggests the appropriate analysis for different networks and funding regimes.

Financial Analysis

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.

Table 5 Analysis 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

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 sealed options. 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.

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.

Economic Analysis

With the economic analysis the benefits (i.e. cost savings) for upgrading to a sealed road are calculated in terms of the savings in agency (usually maintenance), road user, safety, productivity and agricultural costs.

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. Where the B/C ratio of a project is defined as *"The present value (PV) of the public benefits gained divided by the PV of the road agency expenditure"* (Transfund, 2004). This is, the benefits must exceed costs. For most funding situations a B/C of one may not always be affordable so projects are selected 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 sealed roads.

In order to perform an B/C type analysis information about benefits and costs are required. All possible benefits that are experienced in upgrading the unsealed road to a sealed road, need to be included. These benefits may include:

- Road user cost: Vehicle operating cost (VOC) due to reduced roughness, Accident cost, Travel time cost and Passenger discomfort;
- Non-motorized traffic benefits: Time cost of traveler, Operating benefits due to diverted traffic and generated traffic.;
- Increased agricultural production; and,
- Reduction in whole of life cost.

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 the traffic breakeven points for warranting the upgrade from unsealed to sealed roads can be obtained.

6 Application Example

6.1 Background to the Problem

An asset manager is managing a network which largely consists of unsealed roads (80%) and a limited number of sealed 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 sealed 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 the guidelines in Henning, et al (2005) for determining the best option for addressing the farmers concerns. The following sections document the process.

6.2 Step 1: Evaluating the Need to Upgrade

The needs assessment was completed using the score sheet presented in Table 3. The score from the need assessment totals 27 and according to Table 4 there is a definite need to consider this road for an upgrade to a sealed road.

6.3 Step 2 Identify the Surface Options

Table 2 and the criteria in Henning, et al (2005) were 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;
- Seal 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 similar 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; and,
- The maintenance liability of these surface types are well within existing capabilities.

6.4 Step 3: Economic Analysis

Since the road is regionally funded, an economic analysis is required to select the most appropriate surface type.

The capital, maintenance and additional benefits are summarized in Table 6. 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.

Figure 2 illustrates the efficiency frontier for the three surfacing options (a traffic volume of 500 vehicles per day has been assumed).

Table 6 Costs for Each Surfacing Option

Option	Maintain Unsealed	Dust Palliative	Upgrade to Surfaced
Investment Cost ('000 $/km)	0	70	155
Annual Maintenance Cost ($/km-yr)	500	2,500	1,900
Road User Cost ($/V-km)	0.624	0.381	0.271
NM Vehicle Costs ($/V-km)	0.02	0.015	0.01
Additional Benefits ($/km-yr)	0	180	250

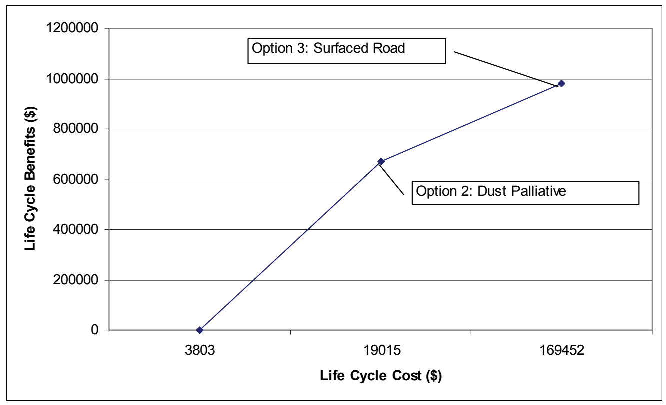

Figure 2 Life Cycle Benefit and Cost Graph

Both the two alternative surfacing options resulted in a positive incremental benefit compared with the base strategy (keep the existing unsealed 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.

7 Recommendations

The surfacing alternatives framework developed offers firm guidelines and yet is 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 which can be used as is with the suggested parameters.

The three steps in the decision framework are:

- 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.
- Select suitable technologies. 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.
- 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.

For further details on the framework and its application see the full report at www.road-management.info.

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