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Comparison of Cost-Effectiveness and Value-for-Money of DCP-DN Pavement Design Method for Low-Volume Roads in Comparison with Conventional Designs

Inception Report

Authors: M I Pinard and G van Zyl

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Infra Africa Consultants
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ReCAP Project Management Unit
Cardno Emerging Market (UK) Ltd
Oxford House, Oxford Road
Thame
OX9 2AH
United Kingdom

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Low-volume roads, pavement design, Dynamic Cone Penetrometer, cost-benefit analysis, life-cycle cost.

Acronyms, Units and Currencies

AfCAP	Africa Community Access Partnership
BS	British Standard
CBA	Cost-Benefit Analysis
CBR	California Bearing Ratio
CSRA	Committee for State Road Authorities
DCP	Dynamic Cone Penetrometer
DN	The average penetration rate in mm/blow of the DCP in a pavement layer
emc	Equilibrium Moisture Content
EOD	Environmentally Optimised Design
HVR	High Volume Road
LIC	Low Income Country
LL	Liquid Limit
LTPP	Long Term Pavement Performance
LVR	Low Volume Road
MESA	Million Equivalent Standard Axles
NPV	Net Present Value
PI	Plasticity Index
PMU	Project Management Unit
ReCAP	Research for Community Access Partnership
RRC	Regional Research Centre
SEACAP	South East Asia Community Access Programme
TMH	Technical Methods for Highways
ToR	Terms of Reference
TPA	Transvaal Provincial Administration
TRL	Transport Research Laboratory
UK	United Kingdom (of Great Britain and Northern Ireland)
UKAid	United Kingdom Aid (Department for International Development, UK)
VFM	Value-for-Money

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1 Executive summary

ReCAP has supported the enhancement of a method of pavement design for low volume roads (LVRs) based on the use of the Dynamic Cone Penetrometer (DCP) in preference to the more traditional methods based on the use of the California Bearing Ratio (CBR). Despite the perceived advantages of this relatively new method of design, they are yet to be fully quantified in practice. This has prompted the letting of a project pertaining to the *"Evaluation of cost-effectiveness and value-for-money of DCP-DN pavement design method for low-volume roads in comparison with traditional designs*".

The main purpose of the project is essentially to evaluate road sections designed in a number of African countries using the DCP-DN method in terms of cost-effectiveness and value-for-money. This will primarily entail the collection and analysis of appropriate road cost data for these road sections in order to determine their life-cycle costs in comparison with the same section of road upgraded to a paved standard using traditional, CBR-based pavement designs. In addition, the project will also evaluate the outcome (uptake) of the DCP-DN method and knowledge as well as its potential impact.

This Inception Report describes the initial phase of the project which principally reviewed the background to the project and carried out a desk study of alternative methods of LVR pavement design as a basis for selecting three CBR-based methods that are commonly used in the Sub-Saharan African region for comparison with the DCP-DN method by means of a life-cycle cost analysis. These methods are:

- TRL Overseas Road Note 31 – *A guide to the structural design of bitumen-surfaced roads in tropical and subtropical countries* (4th Ed. 1993).
- TRH4 – *Structural Design of Flexible Pavements for interurban roads* (COLTO, 1996)
- DCP-CBR (TRL) - *Structural design charts for low volume sealed roads in the SADC region* (Gourley and Greening, 1999).

The report also presents the approach and methodology to be adopted for addressing the overall aims of the project including:

- The method of cost-benefit analysis considered appropriate for use on the project.
- The principles that will be applied for determining the cost-effectiveness of the various LVR design methods under consideration.
- The manner of determining "value-for-money" offered by the various design methods.
- The manner of evaluating the outcome (uptake) of the DCP-DN design method.

Finally, the report provides an updated programme for completing the project in line with the overall project period which runs from 13th November 2017 to 31st May 2018. In accordance with the revised programme, the Draft and Final Evaluation reports will be submitted during the weeks beginning respectively on 23 April and 28 May, 2018.

2 Introduction

2.1 Background

One of the key goals of the Research for Community Access Partnership (ReCAP) is to promote safe and sustainable rural access in Africa and Asia through research and knowledge sharing between participating countries and the wider community. In this regard, the Programme focuses on conducting high quality, applied research that will assist Low Income Countries (LICs) to increase all-weather rural access to poor communities. It builds on the strengths of AFCAP and SEACAP in working alongside partner Governments to encourage high levels of research uptake.

The expected outcome of the Programme is "Sustained increase in the evidence base for more cost effective and reliable low volume rural road and transport services, promoted and influencing policy and practice in Africa and Asia". A key aspect of the attainment of this outcome is the cost-effective provision of low volume roads (LVRs) based on the use of an appropriate pavement design method. To this end, ReCAP has supported the enhancement of a method of pavement design based on the use of the Dynamic Cone Penetrometer (DCP) in preference to the more traditional California Bearing Ratio (CBR)-based design methods. A major difference between these approaches is that the former is based on direct measurement of the in situ shear strength of the material (DN value–resistance to penetration by the DCP cone in mm/blow) whereas the latter is based on an indirect measure of the bearing strength/capacity of the material (CBR- ratio of the force per unit area per minute required to penetrate a soil mass, to the force required for a similar penetration of a standard crushed rock material).

2.2 Motivation for Project

For a variety of perceived advantages, there is, in a number of countries in Africa and Asia, an increasing move away from the more traditional CBR-based approach to the design of LVR pavements, to an approach based on the use of the DCP-DN method of design (Rolt and Pinard, 2016). The main advantages of the DCP-DN method of design are that it:

- Involves the use of relatively low cost, robust apparatus that is quick and simple to use (approx. 30 minutes per test). This allows many measurements of pavement layer thicknesses and strengths to be obtained to provide a comprehensive characterization of the in situ road conditions. This provides a strong statistical basis for design, minimizing the risks of under- or over-design inherent in any method that does not provide sufficient information for a proper statistical analysis.

- Provides improved precision limits compared to the CBR test (Smith and Pratt 1983). The strength (DN) values obtained in the field or the laboratory are inherently more accurate because the DCP provides a virtually continuous strength profile throughout the layer being tested (+/- 150 mm) whereas a CBR test is naturally biased towards the ends of the test mould at a penetration depth of 2.5 or 5.0 mm. Moreover, it has been shown that with reasonable care taken to control testing errors, DCP data can be treated as representative of in situ materials characteristics (Roy, 2007).

- Involves testing actual subgrade strength using the DCP at multiple points along the road at the time of the year when subgrades are weakest as well as under multiple seasonal scenarios in contrast to CBR-testing which is relatively costly and time consuming to carry out, requiring large samples for laboratory testing. Moreover, the entire subgrade to a depth of 800 mm is assessed in situ in 150 mm layers as opposed to the traditional testing of a composite, generally disturbed sample extracted from a specified depth (seldom 800 mm) within the subgrade.

- Avoids the need to convert the DCP-DN values to equivalent CBR values at any stage of the design process which would incur errors due to the relatively poor correlation between DCP and CBR measurements (material specific correlation coefficients ranging from 0.67 – 0.79 (Sampson and Netterberg, 1990).

- Provides a standalone means of improving the quality control of compacted materials from density-based methods, which tend to be slow, potentially hazardous (nuclear gauges) and of uncertain accuracy, particularly where there is a variation in site materials along any tested section (Livneh and Livneh, 2013; Hongve and Pinard, 2016) to stiffness/strength-based methods which allows direct comparison to be made between design and achieved strengths on site (Siekmeier et al, 2009).

- Offers a holistic approach to the provision of LVRs in that the DCP test can be used for field investigations, pavement design, laboratory testing and compaction quality and layer thickness control.

The main limitations of the DCP method that could affect the reliability of the outputs include:

- If the existing pavement contains material that is very coarse the DCP probe may 'hit' a large stone or be deflected sideways creating friction on the shaft resulting in incorrect readings. Therefore, some DCP tests may need to be abandoned or repeated.

- If the pavement contains a cemented layer the DCP will not be able to penetrate. To obtain information about the underlying structure a suitable sized hole must be drilled through the cemented layer without using water for lubrication.

- The DCP tests may be performed poorly (e.g. hammer not falling the full distance, non-vertical DCP, excessive movement of the depth measuring rod, etc.). Any test can be poorly executed and therefore this is not a particular limitation of the DCP test. However, the DCP test is less operator susceptible than many other tests thus reducing the risk of measurement error.

Despite the perceived advantages of the DCP-DN method of pavement design listed above, they are yet to be quantified. This has prompted the letting of a ReCAP project pertaining to the *"Evaluation of cost-effectiveness and value-for-money of DCP-DN pavement design method for low-volume roads in comparison with traditional designs*".

2.3 Purpose and Scope

The main purpose of the project is essentially to evaluate road sections designed in several African countries using the DCP-DN method in terms of cost-effectiveness and value-for-money. This will primarily entail the collection and analysis of construction costs of these road sections in order to determine their life-cycle costs in comparison with the same sections of roads upgraded to a paved standard using traditional, CBR-based pavement designs. In addition, the project will also evaluate the outcome (uptake) of the DCP-DN method and knowledge as well as its potential impact.

As indicated in the Terms of Reference (ToR), the scope of work associated with the attainment of the above objectives is envisaged to include the following tasks:

1. Visit some of the roads in each country to get an appreciation of their in-service performance and current condition. The visits will be coordinated with the respective National Coordinators and the ReCAP Infrastructure Research Manager.

2. Undertake a desk study of the design, construction and maintenance activities that have been carried out on each road section. This will be based on design reports, completion reports (as-built information), monitoring reports, where available, as well as other sources.

3. Compile information on construction costs, maintenance costs and compute life-cycle costs for each road section. Obtain similar information for roads (paved and unpaved) designed to traditional standards for comparison.

4. Prepare an evaluation report providing a comparison of the costs and related in-service performance of the road sections. Provide an in-depth analysis of the comparative cost figures highlighting cost-effectiveness and value-for-money aspects of the EOD approach incorporating the DCP-DN design method.

5. Hold meetings with relevant authorities in-country, where necessary. The ReCAP Infrastructure Research Manager will assist with coordination of the meetings with relevant personnel.

The manner in which the above activities have been incorporated in the implementation of the project is elaborated up in Section 4 of the report – Approach and Methodology.

2.4 Inception Report

In accordance with the project timetable, the initial activity entails the preparation of an Inception Report outlining the proposed approach and methodology for carrying out the assignment, and incorporating the desk study/literature review outcomes. Accordingly, this Inception Report is structured as follows:

Section 1: An Executive Summary that summarises the main findings of the report.

Section 2 (this section): A brief background to the project including its purpose and scope.

Section 3: The outcome of the desk study/literature review of pavement design of low volume roads.

Section 4: The proposed approach and methodology for carrying out the assignment.

Section 5: The programme and project deliverables

Section 6: A summary of the key findings, conclusions and recommendations of the report.

3 Review of Existing Literature on Pavement Design of Low Volume Roads

3.1 General

The purpose of this section is to firstly provide an overview of the various methods that are available for the design of LVRs including the details of the DCP-DN method and traditional methods. The outcome of this review provides the basis for selecting the traditional methods that are most appropriate for comparing with the DCP-DN method in terms of cost-effectiveness and value-for-money.

3.2 Ideal Attributes of LVR Pavement Design Methods

Ideally, an appropriate LVR pavement design method should be based on experience and fundamental theory of structural and material behaviour developed over time. It should also take account of local conditions of climate, traffic, available local materials and other environmental factors. By so doing, it should allow the designer to produce an appropriate pavement structure of sufficient shear strength and bearing capacity to carry the anticipated traffic over its design life to a pre-determined terminal level of service at minimum life-cycle costs.

The following attributes provide a benchmark against which the various available LVR pavement design methods may be evaluated:

- **Subgrade design classes:** Should be narrow to take advantage of the range of strong subgrade materials which predominate over extensive parts of many countries in Africa.
- **Traffic design classes:** Should be narrow to cater incrementally for design traffic loadings in the range up to 1 Million Equivalent Standard Axles (MESA).
- **Materials classes:** Should include a sufficient number of classes to cater for the full range and differing properties of naturally occurring materials (e.g. granite, quartzite, sand, etc.) and pedocretes (e.g. calcrete, laterite) that occur extensively in Africa.
- **Materials specifications**: Should be based on proven field performance in relation to such factors as traffic, subgrade design class, sealed surface design and geo-climatic zone.

Based on the above criteria, the various design methods that may be considered for use in Africa may be evaluated in relation to their appropriateness for application to the design of LVRs as discussed below.

3.3 LVR Pavement Design Methods

There are a number of methods that may be used for the design of LVRs based on both empirical and mechanistic/analytical principles as follows:

3.3.1 Empirical methods

Empirical methods are derived from field studies of pavement performance in which the design is based on some measured or estimated property, such as strength (DN or CBR), where the design limits applied to these properties are related to past successful practice.

Empirically based methods are likely to be satisfactory provided the materials, environment and conditions of loading do not differ significantly from those that prevailed during the original empirical studies on which the designs were based. Thus, the extension of empirical methods to different loadings, different materials and different environmental conditions can be achieved only by carrying out expensive and time consuming full-scale pavement experiments.

3.3.2 Mechanistic/Analytical methods

Mechanistic/analytical methods are derived from theoretical studies of the mechanical behaviour of the pavement in which the design is based on the mechanics of materials that relates an input, such as wheel load, to an output or pavement response, such as stress or strain. The output (stresses and strains) can then be related to traffic load via empirically derived transfer functions to predict pavement life for a wide range of materials and pavement types. Such methods have been used in the preparation of simplified design manuals in which the materials commonly available in the region have been tested and the results used to prepare thickness designs in the form of a catalogue of structures. Past investigations, however, have shown that mechanistic empirical methods are often not appropriate for low volume roads due to inappropriate terminal serviceability criteria and a lack of appropriate transfer functions (Paige-Green, 2015).

3.3.3 Design catalogues

Design catalogues/charts developed from the above methods are the easiest design process to use as all the practical and theoretical work has been carried out and different structures are presented in catalogue form for various combinations of traffic, environmental effects, pavement materials and design options. However, the use of such methods by inexperienced practitioners could lead to failures due to the underlying design assumptions not being fully understood or appreciated.

3.3.4 Available pavement design methods

Table 1 lists the various methods available for the design of LVRs in the Africa region and elsewhere where similar traffic, material types and environmental conditions prevail.

Table 1 – LVR Pavement design methods available for use in Africa

Mechanistic-Empirical Methods	Empirical Methods
S-N Method (1993)	DCP-CBR (1975): Transvaal Provincial Administration (TPA)
TRL ORN31 (1993)	DCP-CBR (1999): TRL
TRH4 design method (1996)	DCP-DN (2012): AfCAP

As with all methods of pavement design, the four main activities of the design procedure are as follows:

- Assessment of subgrade strength
- Assessment of design traffic loading
- Selection of pavement materials
- Determination of pavement layer requirements (thickness and/or strength)

Apart from the determination of traffic loading which is generally quite straight forward, the other aspects of the design procedure all vary quite significantly between the design methods listed above. A brief description of the key features of these methods is provided below:

(a) **S-N Method**

Development: The S-N (Elasto-Plastic) design method (Wolff, 1992) is a mechanistic method based on elastoplastic behaviour of granular pavement materials and bituminous surfacings. It uses non-linear analysis to model the pavement together with empirically derived transfer functions calibrated with HVS testing of in situ pavements to predict the plastic deformation (rutting) in the granular layers. This approach has provided the basis for the development of a catalogue of pavement structures catering specifically to low volume roads. The catalogue is based on a 20 mm rut failure criterion.

The design was verified by comparing the expected life of 23 low-volume road pavement structures as determined from field measurements with expected life of the same pavement structures as determined mechanistically with the S-N design method. The pavement lives calculated were found to compare relatively well. The catalogue includes five traffic classes that range from < 0.005 MESA to 0.8 MESA.

Assessment of subgrade strength: This is based on the soaked CBR value, regardless of climatic zone. A minimum CBR value of 3% at 95% Mod. AASHTO is assumed for design purposes, but lower layers in the catalogue may be omitted if the subgrade CBR strength is higher than 3%

Selection of pavement materials. The approach to the selection of pavement materials does not allow any "relaxation", i.e. less stringent strength requirements, compared with that required for high volume roads (HVRs). The material strength is based on the soaked CBR. In addition, requirements are placed on the allowable plasticity and grading of the material, the limits of which are related to the class of the material, i.e. the higher the class, the more stringent the limits, as stipulated in TRH14 (CSRA, 1985).

Determination of pavement requirements (thickness and/or strength): Pavement layer thickness is constant at 150 mm but layer strengths are varied in relation to the geo-climatic zones – dry/moderate (Weinert N value > 2) and wet (Weinert N value < 2). Thus, for a given traffic loading, the required layer strengths are higher in the wet zone than in the dry/moderate zone.

Use of method: The S-N method is not widely used in South Africa and probably not at all in the rest of Sub-Saharan Africa or Asia.

(b) TRL ORN31

Development

Overseas Road Note (ORN) 31 is based principally on research conducted in Tropical and Sub-tropical countries of the world by the Overseas Centre of the Transport Research Laboratory (TRL) on behalf of the Overseas Development Administration (ODA). The Road Note was first published in 1962 and revised subsequently in 1966, 1977 and 1993. The pavement designs incorporated into the latest (4th) edition of the Road Note are based primarily on:

(a) The results of full-scale experiments where all factors affecting performance have been accurately measured and their variability quantified.
(b) Studies of the performance of as-built existing road networks.

Where direct empirical evidence was lacking designs have been interpolated or extrapolated from empirical studies using road performance models (Parsley and Robinson (1982), Paterson (1987), Rolt et al (1987) and standard analytical/ mechanistic methods.

The latest edition of the Road Note extends the designs of previous editions to cater for traffic up to 30 MESA and takes account of the variability in material properties and construction control and the uncertainty in traffic forecasts as well as the effects of climate and high axle loads and the overall statistical variability in road performance. The catalogue includes six traffic classes for granular materials that range from < 0.3 MESA to 10 MESA with two of the classes (T1 = <0.3 MESA andT2 = 0.3 – 0.7 MESA)) falling with the LVR range.

Assessment of subgrade strength: This is based on the moisture content equal to the wettest moisture condition likely to occur in the subgrade after the road is opened to traffic, i.e. the long-term, in-service, equilibrium moisture content. The strength of the subgrade is divided into six classes ranging from a CBR of 2% (S1) to ≥30% (S6). A minimum CBR value of 3% at 95% Mod. AASHTO is assumed for design purposes, but lower layers in the catalogue may be omitted if the subgrade CBR strength is higher than 3%

Selection of pavement materials. The approach to the selection of pavement materials offers a "relaxation" on strength requirements in arid or semi-arid areas (annual rainfall < 500mm), compared with that required for wet regions (annual rainfall > 500mm). The material strength is based on the soaked CBR of 80% for the basecourse and 30% for the subbase in wet regions. However, in arid or semi-arid regions, the requirements in the basecourse may be reduced to a soaked CBR 60% and in the subbase to a CBR of 30% at the anticipated equilibrium moisture content (i.e. not necessarily the soaked condition). In addition, requirements are placed on the allowable plasticity and grading of the pavement materials, the limits of which are related to the design traffic class and moisture regime, i.e. the higher the class and the wetter the anticipated moisture regime, the more stringent the limits.

Determination of pavement requirements (thickness and/or strength): Pavement layer thickness vary between 100 and 325 mm and layer strengths are varied as discussed above.

Use of Method: ORN31 is probably the most widely used method of pavement design in the tropical and sub-tropical regions of the world including Africa, Asia, Caribbean, Central America and the Far East.

(c) TRH4 method

Development: The Technical Recommendations for Highways (TRH) 4 pavement design method (COLTO, 1996) is based on the South African Mechanistic Design procedure which uses linear elastic analysis to model the pavement in which the stresses and strains that are most likely to initiate failure in a particular material type have been related to traffic load, via appropriate transfer functions, some of which were calibrated from HVS testing. The design catalogue was verified by comparison of the analytically determined performance with the actual field performance of several LVRs. The catalogue includes six traffic classes that range from < 0.003 MESA to 0.8 MESA and can be applied in two climatic zones – dry/moderate (Weinert N value > 2) and wet (Weinert N value < 2). The catalogue is based on a 20 mm rut failure criterion.

Assessment of subgrade strength: This is based on the soaked CBR value, regardless of climatic zone. The strength of the subgrade is divided into four classes ranging from a CBR of 3% (SG3) to 15% (SG1). A minimum CBR value of 3% at 95% Mod. AASHTO is assumed for design purposes, but lower layers in the catalogue may be omitted if the subgrade CBR strength is higher than 3%

Selection of pavement materials. The approach to the selection of pavement materials does not allow any "relaxation" on strength requirements, compared with that required for high volume roads (HVRs). The material strength is based on the soaked CBR. In addition, requirements are placed on the allowable plasticity and grading of the material, the limits of which are related to the class of the material, i.e. the higher the class, the more stringent the limits as stipulated in TRH4 (CSRA, 1985).

Determination of pavement requirements (thickness and/or strength: Pavement layer thickness vary between 100 and 200 mm and layer strengths are varied in relation to the geo-climatic zones – dry/moderate (Weinert N value > 2) and wet (Weinert N value < 2). Thus, for a given traffic loading, layer strengths are higher in the wet zone than in the dry/moderate zone.

Use of Method: TRH4 is widely used, not just in South Africa but, also, in many countries in Sub-Saharan Africa.

(d) **DCP-CBR (TPA)**

Development

The DCP-CBR method of pavement design originated from investigations carried out in the early 1970s in the Transvaal Provincial Administration (TPA) in South Africa. These investigations included the back-analysis of some 3000 km of roads in different traffic (0.04 to 20 MESA) and climatic environments (Burrow, 1975). The original design catalogue of structures was based on the Burrow investigation and incorporated the "pavement strength balance" concept (Kleyn and Savage, 1982; Kleyn and van Heerden 1983; Kleyn and van Zyl, 1987). This catalogue was subsequently incorporated into a South African Department of Transport Manual on Appropriate Standards (DOT, 1993). This layer-strength, CBR-based catalogue caters for traffic loading up to 0.3 MESA and, in essence, entails the integration of the design strength profile optimally with the in situ strength profile as a basis for arriving at the required pavement structure for a given traffic loading. The catalogue is a based on a 20 mm rut failure criterion.

Assessment of subgrade strength: Unlike the more traditional methods of pavement design described above, the DCP-CBR method is based on the in situ value of the subgrade strength under the expected moisture conditions. Where possible, it is preferable to undertake the DCP survey when the moisture regime of the existing pavement coincides with the anticipated "design" moisture regime of the pavement. However, when this is not possible, the DCP results will need to be adjusted in relation to the in situ moisture conditions prevailing at the time of the DCP survey compared with the anticipated long-term, in-service moisture conditions (i.e. design moisture content which is essentially the equilibrium moisture content – emc) after the road has been upgraded. Another advantage is that the entire subgrade to a depth of 800 mm is assessed in 150 mm layers as opposed to the traditional testing of a composite sample extracted from a specified depth (seldom 800 mm) within the subgrade.)

Selection of pavement materials. The approach to the selection of pavement materials does allow a "relaxation" in strength compared with that required for high volume roads (HVRs). The material strength is based on the CBR values based on the anticipated emc. In addition, requirements are placed on the allowable plasticity and grading of the material, the limits of which are related to the class of the material, i.e. the higher the class, the more stringent the limits, as stipulated in TRH14 (CSRA, 1985).

Determination of pavement requirements (thickness and/or strength): Pavement layer thickness are constant at 150 mm but layer strengths are varied in relation to traffic loading. Thus, layer strengths increase gradually in relation to an increase in design traffic loading.

Use of Method: The use of the DCP-CBR (TPA) method has been almost, if not, exclusively been in South Africa. However, it is now being replaced by the DCP-DN (AfCAP) method which incorporates many of its design principles.

(e) DCP-DN (AfCAP)

Development

Subsequent to the development of the DCP-CBR (TPA) approach described in section 3.3.4 (c), additional investigations were undertaken in the mid-1990s of some 57 LVRs in South Africa which largely corroborated the original DCP-CBR catalogue developed by the TPA (Paige-Green 1994, 1999) and formalised the adoption of the pavement balance concept (De Beer, Kleyn and Savage, 1988; Kleyn and Steyn, 2010). This catalogue was subsequently modified and enhanced under AfCAP largely because of the poor correlation between CBR and DCP measurements (material specific correlation coefficients ranging from 0.67 – 0.79. (Sampson and Netterberg, 1990) and inconsistencies in the CBR test. Thus, the new catalogue was based solely on the DN value as measured in the field and laboratory (Pinard et al, 2015a, 2015b). In addition, the pavement structures and DN values in the original TPA catalogue were adjusted slightly to improve pavement balance. Also, based on the additional information obtained from the investigation of the 57 LVRs mentioned above, the catalogue was extended to include Layer Strength Diagrams up to 1 MESA.

Assessment of subgrade strength: This is as described above for the DCP-CBR method. Selection of pavement materials. Unlike the more traditional CBR-based methods of pavement design, the selection of the pavement materials is based solely on the use of the DN value at the anticipated emc in the pavement of the upgraded road. Moreover, no specific requirements are placed on the allowable plasticity and grading of the material as it is assumed that, within certain limits (specified maximum and minimum Grading Modulus values) the DN value is a composite measure of the key variables that affect its strength, i.e. compacted density, moisture content, grading and plasticity.

Determination of pavement requirements (thickness and/or strength): In the standard catalogue, pavement layer thicknesses are constant at 150 mm but layer strengths are varied in relation to traffic loading. Thus, layer strengths increase gradually in relation to an increase in design traffic loading. However, the design method can be adapted for any selected layer thicknesses or materials available.

Use of Method: The DCP-DN (AfCAP) method is being used increasingly in a number of African countries and, more recently, in Asia (India).

(f) **DCP-CBR (TRL)**

This design approach was based on the outcome of a 4-year "Collaborative Research Programme on Highway Engineering Materials in the SADC Region" (Gourley and Greening, 1999). The overall aim of the programme was to investigate the use of natural gravels for road bases and to recommend innovative approaches for their use in a way that is cost-effective and environmentally sensitive.

Sections of road were selected on the existing road networks in Botswana, Malawi and Zimbabwe, and these were tested and monitored to enable designs to be evaluated. The research focused on measuring how road pavements performed with time and traffic, and in different climatic conditions. It also identified features which need to be included in the road design to minimize risk including environmental influences, the performance of "non-standard" materials and actual modes of deterioration.

The output of the research programme was the development of a set of new structural design charts and a materials design procedure for LVRs. The catalogue includes six traffic classes that range from < 0.003 MESA to 3 MESA and can be applied in two climatic zones – dry/moderate (Weinert N value > 4) and wet (Weinert N value < 4).

Assessment of subgrade strength: The subgrade strength is classified into five classes ranging from a soaked CBR of 3-4% (Class S2) to 30% (Class S1). The design subgrade strength is based on the in situ worst case long term conditions similar to that obtained in the laboratory soaked CBR test. However, in a dry/moderate climate it is assumed that the subgrade strength value is doubled which is equivalent to a shift upwards of one subgrade class (Gourley, 2002). The CBR values are converted to DN values, based on the TRL DCP-CBR correlation, for input into a CBR catalogue

Selection of pavement materials. The approach to the selection of pavement materials does allow a "relaxation" on strength requirements, compared with that required for high volume roads (HVRs). In addition, requirements are placed on the allowable plasticity and grading of the material, the limits of which are related to the class of material, i.e. the higher the class, the more stringent the limits and the type of material, i.e. different for pedogenic and non-pedogenic materials.

Determination of pavement requirements (thickness and/or strength): Pavement layer thickness are variable and range from 120 mm to 275 mm. The material strength is based on the soaked CBR, regardless of climate. However, as discussed above, the effect of climate is accounted for by changing the thickness and/or quality of the materials in relation to the geo-climatic zones – dry/moderate (Weinert N value > 4) and wet (Weinert N value < 4). Thus, for a given traffic loading, layer strengths and/or thicknesses are higher/greater in the wet zone than in the dry/moderate zone.

(g) **Other LVR design methods**

In addition to the above generically-developed methods of pavement design, there are other country specific methods which have been developed for the design of LVRs in particular countries. The most prominent ones are as follows:

- Zimbabwe Pavement Design Guide (1975)
- Botswana Roads Design Manual (1982)
- Kenya Manual for the Provision of Low Volume Roads (TRL 2016).

All of the above methods are essentially country specific guidelines or manuals based on empirical or mechanistic empirical studies.

3.3.5 Comparison of design methods

Comparison between different design methods is not straight forward for various reasons, including:

- **The use of fundamentally different design assumptions,** e.g. empirical versus mechanistic/ analytical. It is noteworthy that the layered linear elastic theory assumed in the latter approach is based on the assumption that the materials are isotropic and elastic, an assumption that is more valid for relatively stiff, typically processed, pavement materials under low stress conditions. Such assumptions are unlikely to be valid for the relatively thin pavement structures typically comprising relatively variable, naturally occurring materials that are used in LVRs.

- **The use of differently defined geo-climatic conditions.** For example, based on the Weinert N value which correlates broadly with mean annual rainfall and macro-climate, and gives an indication of the overall availability of moisture during the year, the TRH4 design approach assumes N < 2 for wet climates, N = 2 - 5 for moderate climates and N > 5 for dry climates whereas TRL/SADC (DCP-CBR) design approach assumes N < 4 for wet climates and N > 4 for dry/moderate climates.

- **The use of a different range of traffic loading for various traffic classes,** some of which coincide and some of which don't, as illustrated in Table 2 for the various design methods described above in terms of traffic classes and respective traffic ranges.

Table 2 – Traffic class and related traffic range for different design methods

Design Method	Traffic Class (Range of Cumulative ESAs x 10^6 in one direction)					
TRH4 S-N	0.01 (< 0.01)	0.03 (0.01 - 0.03)	0.1 (0.03 – 0.1)	0.3 (0.10 – 0.3)		1.0 (0.3 – 1.0)
DCP-CBR	0.01 (< 0.01)	0.05 (0.01 – 0.05)	0.1 0.05 – 0.10	0.3 0.10 – 0.30	0.5 0.30 – 0.50	1.0 0.50 – 1.0
ORN31				0.30. 0.10 – 0.30	0.70 0.30 – 0.70	
DCP-DN	0.01 (< 0.01)	0.03 (0.01 – 0.03)	0.10 (0.03 – 0.10)	0.30. 0.10 – 0.30	0.70 0.30 – 0.70	1.0 0.70 – 1.0

- **The use of different assumptions regarding the subgrade design moisture content.** For example, TRH4 assumes soaked conditions regardless of climate whereas DCP-DN assumes anticipated long-term in situ moisture conditions (may be soaked or unsoaked).

- **The use of different specification limits for materials selection.** For example, some methods (e.g. TRH4, S-N, DCP-CBR) require simultaneous compliance with strength, grading and plasticity criteria, whereas others (the DCP-DN method) require compliance only with a DN value which, within limits related to Grading Modulus and is assumed to provide a composite measure of the key variables that affect performance, i.e. moisture, compacted density, grading and plasticity.

- **The use of different test methods**. For example, TRH4 is based on the TMH1 test methods (CSRA, 1987) DCP-CBR (TRL) on BS Test Methods (British Standards Institution, 1990) and DCP-DN on South African SANS methods (essentially a revision of TMH1) (SABS, 2012). These test methods are not comparable in that there are significant differences in procedure which produce quite different results leading to inconsistencies in the quality of materials incorporated in the road works. For example, all other factors being equal, the LL and, hence, PI determined using the BS LL device are 4 units higher than those determined using a TMH1 LL device (Sampson and Netterberg, 1984). Similarly, all other factors being equal, CBRs determined by the TMH1 methods are, on average, about 20% lower than the same material tested by the BS test method (Pinard and Netterberg, 2012).

The above differences emphasise the importance of, as far as possible, comparing "apples with apples" in terms of choosing, as far as practicable, similar input variables associated with the use of the design methods and, importantly, adopting a "synthetic" approach as presented in Section 4.

3.3.6 Selected pavement design methods for comparison

The criteria that have been used to select the traditional design approaches for comparison with the DCP-DN approach are as follows:

- Developed specifically for LVRs
- Developed for generic rather than country-specific application
- Widely used in the African region

From the available methods listed in Table 1, and based on the above selection criteria, the design methods that merit consideration for comparison with the DCP-DN method in terms of cost-effectiveness and value-for-money are:

- ORN31
- TRH4
- DCP-CBR (TRL)

Details of the DCP-DN, ORN31, TRH4 and DCP-CBR design methods are well documented in the literature and are not repeated in this report. However, for ease of reference, the design catalogues of these methods are presented in Annexes 1 - 4.

The other design methods listed in Table 1 have been excluded from consideration for the following reasons:

(a) S-N Method: This method is not commonly used in the African region
(b) DCP-CBR (TPA): This method has now been superseded by the DCP-DN method

The approach and methodology that has been adopted for undertaking the evaluation of cost-effectiveness and value-for-money of the DCP-DN pavement design method for low-volume roads in comparison with traditional designs (TRH4 and DCP-CBR) is presented in the next section.

4 Approach and Methodology

4.1 General

A fair, equitable and transparent approach to undertaking the evaluation of cost-effectiveness and value-for-money of the DCP-DN method of pavement design for LVRs in comparison with traditional design methods is essential, if the outputs are to be credible. To this end, this section presents the following:

- The method of cost-benefit analysis considered appropriate for use on the assignment.
- The principles that will be applied for determining the cost-effectiveness of the various LVR design methods under consideration.
- The manner of determining "value-for-money" offered by the various design methods.
- The manner of evaluating the outcome (uptake) of the DCP-DN design method.

4.2 Comparative Cost Evaluation

The approach envisaged in the ToR for undertaking a comparative cost evaluation of the alternative methods of pavement design for upgrading from an unpaved (gravel) road standard to a paved standard is essentially as follows:

1) Determine up-front costs as well as life-cycle costs (LCC) of upgrading from an unpaved (gravel) road to a paved road based on:

   (a) the use of the DCP-DN method, and

   (b) the use of selected traditional design method

2) Compare the costs derived from (a) and (b).

In general, LCC include all costs anticipated over the life (or analysis period) of the road. The principal components of such an analysis would typically include the following:

- initial construction costs
- future maintenance costs
- benefits due to savings in user costs over the analysis period.

In order to convert all the costs and benefits that may occur at different times throughout the life of each option, a discounted cash flow technique may be used to determine the Net Present Value (NPV) of each option on which basis the preferred option can be determined.

4.2.1 Construction costs

For a given road with a specific design traffic loading that is located in a particular road environment (terrain, subgrade conditions, moisture regime, etc.), the unit cost of construction will depend primarily on the type of pavement structure required by the particular design method in terms of quality/thickness of the pavement layers. Such costs can be obtained with a fair degree of accuracy for a number of DCP-DN designed roads in which the project team were involved in the following countries:

- Ghana
- Kenya
- Malawi
- Tanzania
- South Africa
- Zambia

4.2.2 Maintenance costs
On the assumption that the design and construction of the LVRs have been reasonably well undertaken by either the DCP-DN or traditional design methods, it should be expected that, for a given design traffic loading and road environment, the required maintenance interventions and their timing would be essentially the same for a well-constructed, appropriately-selected surfacing type.

4.2.3 Road user costs
On the assumption that the design and construction of the LVRs have been reasonably well undertaken by either the DCP-DN or traditional design methods, and that a similar, typical bituminous surface treatment is used (e.g. Cold Mix Asphalt, Cape Seal, Double Surface Dressing, etc.) it should be expected that road user costs, which are dominated by the roughness of the pavement, would be essentially the same.

4.2.4 Life-cycle costs
Based on the discussion presented in Sections 4.2.1, 4.2.2 and 4.2.3 above, it is apparent that, for a given design traffic loading and road environmental conditions, the difference in LCC will be related directly to the difference in initial construction costs. In turn, such costs will be related directly to the type of pavement structure (layer strength/quality and thickness) dictated by the design method adopted, as both the maintenance and vehicle operating costs can be assumed to be essentially the same for any of the road design options.

4.3 Cost-effectiveness of LVR design methods

4.3.1 General approach
The principle that will be applied in determining the cost-effectiveness of the various LVR design methods discussed in Section 3.3.6 is to simply to determine the cost ratios for pavement structures derived from the DCP-DN method versus those derived from the traditional design methods. In this regard, the same unit costs of construction for the DCP-DN designed roads will be applied to the traditional design methods by which means the cost ratios will be derived between the DCP-DN and other traditional design methods (TRH4 and DCP-CBR). The general approach is illustrated in Figure 1.

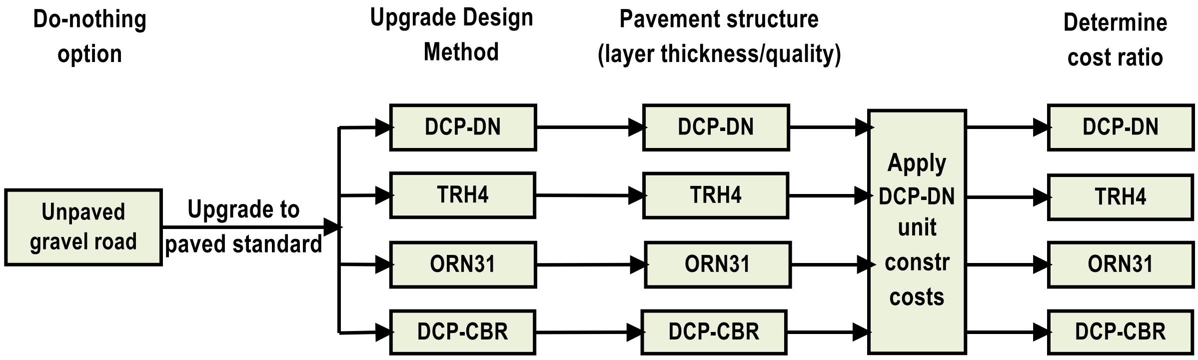

Figure 1 – General procedure for determining cost-effectiveness of various LVR design methods

4.3.2 Design variables
The key design parameters required as inputs for the design methods that will need to be considered in the evaluation matrix include:

(a) **Design traffic loading:** Three design traffic loadings have been chosen which are common to all the methods being evaluated as follows (ref. Table 1):

i. Low = Traffic class 0.1 MESA
ii. Medium = Traffic class 0.3 MESA
iii. High = Traffic class 1.0 MESA

(b) **Subgrade strength:** Three strengths spanning weak, moderate and strong subgrades have been chosen as follows:
   I. Weak: CBR = 3%
   II. Medium: CBR = 7 %
   III. Strong: CBR = 15%

(c) Climate: Two broadly demarcated climatic regimes, differentiated by the Weinert N Value will be considered as follows:
   I. Dry/moderate (N > 2)
   II. Wet (N < 2)

(d) Other factors. A number of project specific factors may also need to be considered in each of the road sections being evaluated:
   I. Earthworks required (including additional material for drainage improvement)
   II. Quality of materials close to the project
   III. Cost of importing base/ subbase material as required by the DCP-DN and traditional designs

4.3.3 Evaluation procedure

Using the above parameters, a matrix of DCP-DN and traditionally designed pavement structures can be generated and the ratio of costs calculated for similar situations (each cell in the evaluation matrix). The evaluation procedure is illustrated in the form of a flow chart as presented in Figure 2.

Ultimately, the cost ratios for a DCP-DN designed road located in a variety of road environments with that of a traditional design (TRH4 and DCP-CBR) in similar road environments can be calculated.

Following verification of the matrix ratios, this matrix could then be used as a guideline for comparing the cost of DCP-DN and traditional designs for roads located in a variety of road environments.

As would be apparent from the evaluation procedure described above, some of the activities listed in the scope of work in the ToR will not be required. For example, as regards Task 3 (ref. Section 2.3):

- There will be no need to compile information on maintenance costs for each road section, as discussed in Section 4.2.2 above. However, where available, it will be collected for the benefit of the LTPP monitoring process of the Regional Research Centres (RRCs).
- There will be no need to compile information on construction and maintenance costs, and compute life-cycle costs for unpaved roads as such roads are deemed to be the “do-nothing” option which would be common to all the design methods being evaluated.

The exclusion of the above activities from the scope of work will not in any way affect the objective of the project – essentially to evaluate road sections designed in a number of African countries using the DCP-DN method in terms of cost-effectiveness and value-for-money as against traditional methods.

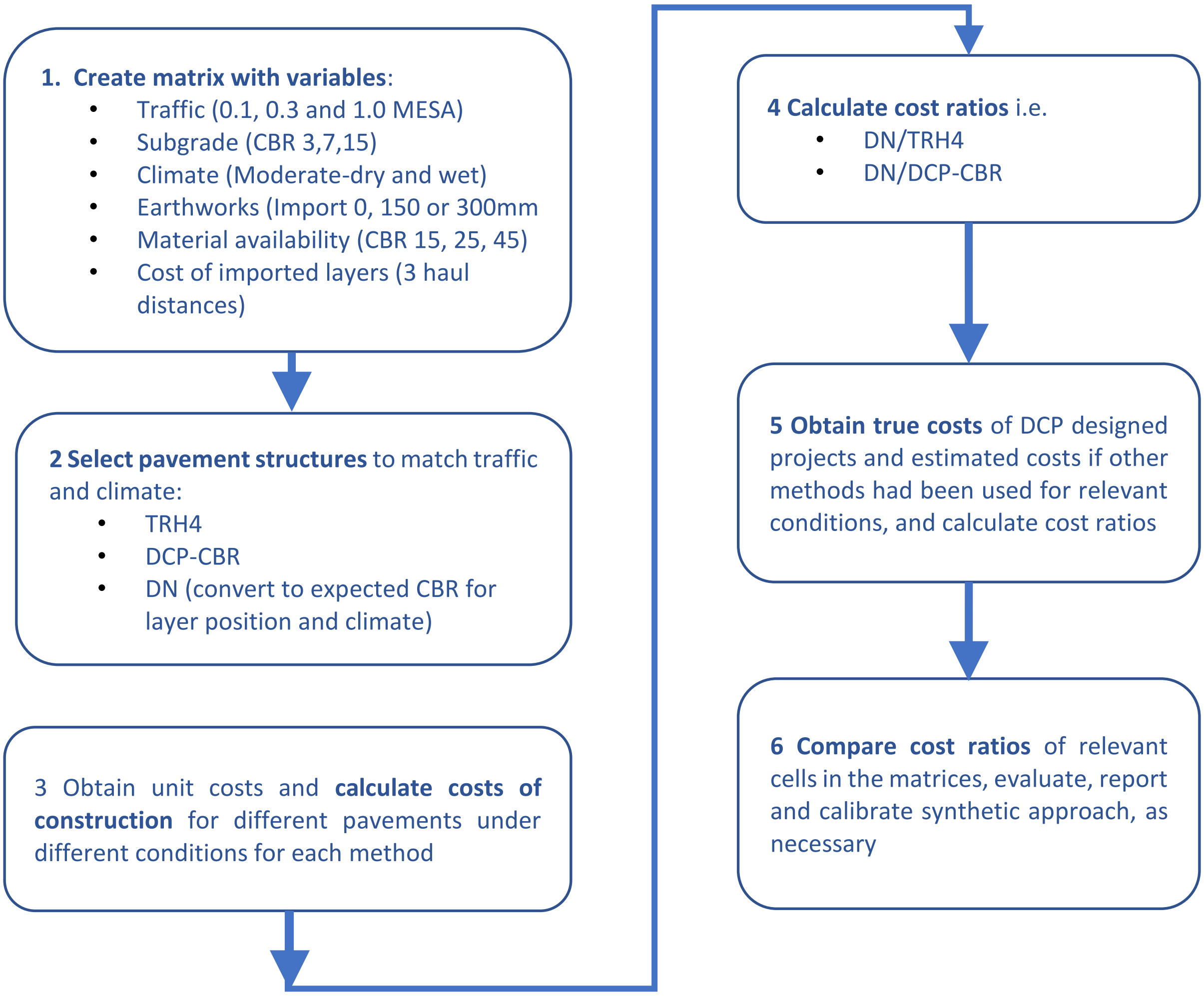

Figure 2 – CBA Evaluation procedure

An example of the matrix compiled for TRH4 (only medium traffic scenario) is displayed in Figure 3.

					Design by	TRH4					
					Base	100 G4 (80)		100 G4 (80)		100 G4 (80)	
					Subbase	125 G6 (25)		125 G6 (25)		125 G6 (25)	
					Selected					150 G9 (7)	
					Subgrade	G7 (15)		G9 (7)		G10 (3)	
					Constr cost	Rip, shape recompact + process 2 layers (225mm)				Rip, shape recompact + process 3 layers (375mm)	
Design Input Prameters											
Traffic						**Medium (100 000 - 300 000 ESAs)**					
Subgrade						Good (G7)(15)		Fair (G9)(7)		Poor (G10)(3)	
Moisture regime/ climate						Dry -Moderate	Wet	Dry -Moderate	Wet	Dry -Moderate	Wet
Existing Drainage improvement/ earthworks required (Min CBR 7 Fill material imported)	High (300mm import)	Available materials/ Free haul	G7 (15)	Cost of layer/s import	Low	B(100-80L) SB(125-25L) (EH-15N) RR	B(100-80L) SB(125-25L) (EH-15N) RR	B(100-80L) SB(125-25L) (EH-15N) RR	B(100-80L) SB(125-25L) (EH-15N) RR	B(100-80L) SB(125-25L) S(150-15N) (EH-15N) RR	B(100-80L) SB(125-25L) S(150-15N) (EH-15N) RR
					Medium	B(100-80M) SB(125-25M) (EH-15N) RR	B(100-80M) SB(125-25M) (EH-15N) RR	B(100-80M) SB(125-25M) (EH-15N) RR	B(100-80M) SB(125-25M) (EH-15N) RR	B(100-80M) SB(125-25M) S(150-15N) (EH-15N) RR	B(100-80M) SB(125-25M) S(150-15N) (EH-15N) RR
					High	B(100-80H) SB(125-25M) (EH-15N) RR	B(100-80H) SB(125-25M) (EH-15N) RR	B(100-80H) SB(125-25M) (EH-15N) RR	B(100-80H) SB(125-25M) (EH-15N) RR	B(100-80H) SB(125-25M) S(150-15N) (EH-15N) RR	B(100-80H) SB(125-25M) S(150-15N) (EH-15N) RR
			G6 (25)	Cost of layer/s import	Low	B(100-80L) SB(125-25N) (EH-25N) RR	B(100-80L) SB(125-25N) (EH-25N) RR	B(100-80L) SB(125-25N) (EH-25N) RR	B(100-80L) SB(125-25N) (EH-25N) RR	B(100-80L) SB(125-25N) S(150-25N) (EH-25N) RR	B(100-80L) SB(125-25N) S(150-25N) (EH-25N) RR
					Medium	B(100-80M) SB(125-25N) (EH-25N) RR	B(100-80M) SB(125-25N) (EH-25N) RR	B(100-80M) SB(125-25N) (EH-25N) RR	B(100-80M) SB(125-25N) (EH-25N) RR	B(100-80M) SB(125-25N) S(150-25N) (EH-25N) RR	B(100-80M) SB(125-25N) S(150-25N) (EH-25N) RR
					High	B(100-80H) SB(125-25N) (EH-25N) RR	B(100-80H) SB(125-25N) (EH-25N) RR	B(100-80H) SB(125-25N) (EH-25N) RR	B(100-80H) SB(125-25N) (EH-25N) RR	B(100-80H) SB(125-25N) S(150-25N) (EH-25N) RR	B(100-80H) SB(125-25N) S(150-25N) (EH-25N) RR
			G5 (45)	Cost of layer/s import	Low	B(100-80L) SB(125-45N) (EH-45N) RR	B(100-80L) SB(125-45N) (EH-45N) RR	B(100-80L) SB(125-45N) (EH-45N) RR	B(100-80L) SB(125-45N) (EH-45N) RR	B(100-80L) SB(125-45N) S(150-45N) (EH-25N) RR	B(100-80L) SB(125-45N) S(150-45N) (EH-25N) RR
					Medium	B(100-80M) SB(125-45N) (EH-45N) RR	B(100-80M) SB(125-45N) (EH-45N) RR	B(100-80M) SB(125-45N) (EH-45N) RR	B(100-80M) SB(125-45N) (EH-45N) RR	B(100-80M) SB(125-45N) S(150-45N) (EH-45N) RR	B(100-80M) SB(125-45N) S(150-45N) (EH-45N) RR
					High	B(100-80H) SB(125-45N) (EH-45N) RR	B(100-80H) SB(125-45N) (EH-45N) RR	B(100-80H) SB(125-45N) (EH-45N) RR	B(100-80H) SB(125-45N) (EH-45N) RR	B(100-80H) SB(125-45N) S(150-45N) (EH-45N) RR	B(100-80H) SB(125-45N) S(150-45N) (EH-45N) RR
	Similar to the above with Medium (150mm import)										
	Similar to the above with Low (0mm import)										

Figure 3: Pavement construction requirements

A brief explanation of the "Green Cell" is as follows:

TRH4 requires for 0.3 MESA in a dry-moderate environment, on a good subgrade material (CBR 15% Selected), the import and compaction of:

- Fill - 300 mm
- Subbase - 125 mm (G6) material with CBR = 25%
- Base - 100 mm (G4) material with CBR = 80%

Note: In order to calibrate the synthetic model with the selected constructed roads, the fill thickness will be a variable, which could be changed by the user.

In this particular case, a G6 material is available from a borrow pit nearby (free haul distance), which could be used for both fill (average 300 mm – EH denotes Earthworks High) to obtain proper drainage and to construct the subbase. Cost of material procurement only comprises "ex-borrow pit" costs with no haul costs.

The required G4 100 mm base (CBR = 80%) must be obtained from a source at medium distance, as denoted (100-80M i.e. base of 100mm with CBR = 80% from a Medium distance). The total cost of material procurement for this layer comprises:

- "ex-borrow pit" costs
- haul cost m^3 km (medium cost)

Note: Haul distance will be a variable in a "look-up" table, which could be changed by the user.

Construction costs for this particular scenario will comprise:

- Forming of side drains
- Rip and recompaction of the in situ material
- Spread, processing and compaction of:
    - 2 x 150 mm fill material
    - 125 mm subbase
    - 100 mm base

A similar procedure will be followed to obtain pavement structures and construction costs using the DCP-DN and the DCP-CBR methods.

Using the same matrix, the cost ratios (refer Item 4 in Figure 2) will be calculated.

Each of the road sections to be evaluated from the various countries will exhibit specific road environment characteristics that will match the conditions of a cell in the evaluation matrix, except for differences in the required fill volumes and unit costs. The evaluation spreadsheets will be developed in such a way that these values could be changed to obtain the true ratios for each case study.

This exercise will allow calibration/ adjustment to the theoretical matrix.

Following verification of the matrix ratios, this matrix could then be used as a guideline to determine the cost-effectiveness of the DCP/DN design methodology.

4.4 Determination of Value-for-Money

4.4.1 General

The UK Department for International Development (DFID) defines Value for Money (VFM) as "maximising the impact of each pound spent to improve poor people's lives" (DFID, 2011). This echoes the UK National Audit Office's definition which defines VFM as being "the optimal use of resources to achieve intended outcomes". A key element in both definitions is to make the best use of available resources to achieve sustainable outputs and outcomes.

4.4.2 Framework for VFM analysis

The VFM conceptual framework is based on a logical "results chain" which explicitly sets out the results to be achieved by a given programme or project. Figure 4 presents the five main elements of this results chain and shows where the four main dimensions of VFM can be measured.

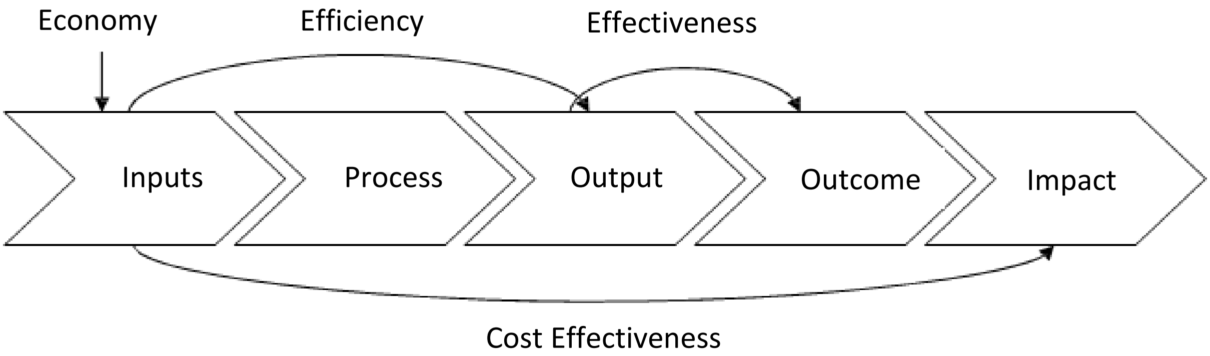

Figure 4 – Framework for VFM analysis (DFID, 2011)

The five main elements of the VFM framework are as follows:

1) **Inputs** – the resources used, in terms of finance and staff time (capital and labour).
2) **Process** – the process by which inputs are transformed into results.
3) **Outputs** – the direct deliverables of the project.
4) **Outcomes** - resulting from the outputs
5) **Impacts** - the longer-term impact of the project.

In essence, the elements represent a chain of events through time, given that these different types of results would usually, but not always, take place sequentially. The causal links between these different types of results need to be informed by evidence, however, as a sustained actual outcome or an impact in the programme area may be influenced by factors outside the programme.

The main dimensions of the VFM framework are as follows:

(a) **Economy:** Relates to the price at which inputs are purchased. For example, are DFID's agents buying inputs (e.g. consultancy services) at the appropriate quality and the right price?

(b) **Efficiency:** Relates to how well inputs are converted into a specific output, i.e. the results delivered by DFID's agents to an external party such as a partner country.

(c) **Effectiveness**: Relates to how well outputs from an intervention are converted into sustained outcomes and achievement of the ultimate desired outcome on poverty reduction. Note: In contrast to outputs, the implementer does not exercise direct control over whether actual outcomes materialise and whether they can be sustained.

(d) **Cost-effectiveness:** Relates to the cost of achieving intended project actual outcomes. This can be used to compare the cost of alternative ways of producing the same or similar outcomes.

In practice, in order to obtain value-for-money on any project it would be necessary to maximise its effectiveness, efficiency and economy (the 3 Es) as well as the strength of the links in the results chain. The issue of equity also needs to be considered to make sure that the outcomes of the project are not only sustainable but, importantly, they are targeted at the poorest and include sufficient gender targets.

4.4.3 Project requirements

In accordance with the ToR, a key requirement of the project is to evaluate road sections designed using the DCP-DN method in terms of the following dimensions of VFM:

- cost-effectiveness
- outcome (uptake) and knowledge
- potential impact.

The proposed approach for addressing the above requirements is discussed below:

(1) Cost-effectiveness

The cost-effectiveness of the DCP-DN method of design, as against other typical methods of design (TRH4 and DCP-CBR (TRL) will be determined simply on the basis of the construction cost ratio of the former versus the latter (ref. Section 4.3) based on selected road sections from various countries (ref. Section 4.2.1).

(2) Outcome (uptake) and knowledge

In line with one of the key aims of ReCAP, the project outcome is expected to *promote sustained increase in the evidence base for more cost effective and reliable provision of LVRs as well as to influence policy and practice in Africa and Asia.* Thus, the outcome of the project can be assessed in relation to such factors as:

(a) **Sustainability** in terms of such aspects as:

i. Active engagement with the local role players, e.g. through Working Groups or Steering Committees to engender technology transfer, etc.

ii. Strong contribution in kind from partner Governments (e.g. staff time, construction of trial sections, co-funding of research (possibly with other bi-lateral donors, etc.)

iii. Availability of a cadre of trained, motivated practitioners who will mainstream the DCP-DN method of design in their organisations.

(b) **Uptake** in the form of concrete examples of change such as:

i. Partner country's financing of LVRs based on the DCP-DN design method.

ii. Revision of local standards and specifications to comply with the requirements of the DCP-DN design method.

(c) **Quality** of the research in the form of, for example:

i. Number of citations in academic journals.

(d) **Knowledge** of the DCP-DN method in the form of, for example:

i. The number of certified trainers who have themselves applied the method in practice in their countries.

ii. Incorporation in curriculum of tertiary institutions including universities and technical colleges.

(3) Potential impact:

The longer-term potential impact of the project, i.e. the sustained use of the DCP-DN method of design, could include such socio-economic aspects as:

I. Reduced costs/increased cost-effectiveness of LVR provision.

II. Optimum use of non-renewable resources (gravel materials).

III. Improved transport services at cheaper costs.

IV. Increase in agricultural production and productivity

V. Improvements in education and health (being able to access facilities).
VI. Increased resilience to climate impacts
VII. Ultimately, poverty reduction in the vicinity of the project area.

It must be stressed, however, that since the oldest DCP-DN designed sections have been in service for only about 5 years, and some of the others not even constructed, it is most unlikely that in such a relatively short time there would be any discernible, quantifiable impacts of any kind which, in any case, would essentially be the same for all the design methods. Nonetheless, it may be possible to provide a qualitative indication of some of the potential impacts listed above from interviews with local communities.

Notwithstanding the above, the project could be the foundation upon which RRCs become involved in the VFM process throughout the design life (10 – 15 years) of the road sections. Thus, a similar data collection exercise, including maintenance costs, could be undertaken say after 5 years which would provide valuable information on the extent to which they provide VFM as discussed in Section 4.4.

4.5 Data Collection

4.5.1 General

Sections 4.2 to 4.4 have outlined the approach and methodology for undertaking the comparative cost evaluation, cost-effectiveness and value-for-money of the DCP-DN method in relation to the selected alternative methods [TRH4 and DCP-CBR (TRL)]. In this regard, the approach and methodology for collecting the data required to undertake these evaluations is presented in the next section.

4.5.2 Data for road section design

An intimate familiarity with the details of the DCP-DN designed road sections is an essential starting point for undertaking the subsequent cost evaluations described in Sections 4.2 and 4.3. These details include the various variables contained in Cell 1 of Figure 2 – Evaluation procedure. Fortunately, the members of the project team were involved in the DCP-DN design of all of the road sections to be evaluated and the details are documented fully in the relevant design reports.

The details of the proposed 10 road sections for which the data will be collected are shown in Table 3. The criteria for selecting these roads are as follows:

1) Availability of reliable design and construction costs data.
2) Road section length to be at least 0.5 km.
3) Variety of road environments (e.g. climate, terrain, drainage, material types, etc).
4) Road construction undertaken by competitively selected contractor (rather than by force account/in-house construction unit).

Table 3 – Road sections to be evaluated

Country	Road Section		
	Name	Length (km)	Date of constr.
Ghana	- Akyem Kukurantumi – Asafo (Eastern Region)		Not yet started
Malawi	- Kasinje-Kandau (Ntcheu District) - Mwanza-Kunenekude (Mwanza District) - Parachute Batallion-Lifuwu (Salima District) - Linthipe-TC-Lobi	8.5 8 8 5	2016 2016 2016 Not yet started
Kenya	- D379-Wamwangi	450m	2012
Tanzania	- Lawate- Kibongote (Siha District)	14 km	2012
S. Africa	- Danger Point road 4019 (Western Cape) - Nelshoogte road (R38 – Nelshoogte Sawmill)	5.5 6.5	2003 1990
Zambia	- T2 – Waitwika – D1 (Nakonde District)	1 km	Not yet started

4.5.3 Data for cost evaluation and effectiveness

As indicated in Section 4.2, the primary requirement for undertaking a LCC analysis of the various road sections is to obtain the unit cost of their construction. To this end, such data will be collected during the field visits and will be thoroughly checked to ensure its reliability. This will entail discussions with the roads agencies under whose jurisdiction the construction of the road sections was undertaken.

In order to ensure that all the road sections are being evaluated on a similar basis, it will be necessary to ensure that same costs elements are considered, i.e. those costs that relate primarily to the construction of the pavement structure. Thus, variable costs, such as those related to overheads or P & Gs, or to the construction of major elements, such as bridges, will not be included.

For the reasons stated in Sections 4.2.2 and 4.2.3, data on maintenance or road user costs will not be required for the LCC analysis. However, as indicated in Section 4.3.3, such data will still be collected for the benefit of the LTPP monitoring process of the RRCs. Also, whilst the performance of the sections may be of some interest, this information will play no part in the LCC analysis simply because such performance is unlikely to be a reflection only of the efficacy of the design method used and could be as a result of a number of other factors, including faulty design assumptions (e.g. incorrect estimation of design traffic loading), poor construction quality, lack of, or insufficient maintenance, overloading, etc., the assessment of which is outside the scope of this project. Nonetheless, as is the case with maintenance data, general performance information (visual assessment) will be recorded for the benefit of the LTTP monitoring process of the RRCs.

4.5.4 Data for evaluating outcome (uptake) of DCP-DN design method

The data to be collected is related to the various factors listed in Section 4.4.3 (2) and will be collected during the course of the project via discussions with relevant stakeholders.

4.5.5 Data for evaluating the impact of the use of the DCP-DN design method

The data to be collected is related to the various factors listed in Section 4.4.3 (3) and will be collected to the extent available during the course of the project via discussions with relevant stakeholders.

4.5.6 Coordination of data collection

The project team will work closely with the ReCAP PMU and local stakeholders in each of the countries to be visited. Accordingly, the field visits will be coordinated with the respective National Coordinators and ReCAP Infrastructure Research Manager prior to the commencement of data collection. Moreover, in order to engender buy-in, we would propose to establish a Working Group comprising key role players on the project such as the roads agencies and, where possible, the contractors who were involved in the tendering for the construction of the road sections.

5 Work Programme

5.1 General

Following the team meeting that was held at the start of the project, the approach and methodology outlined in the Consultant's Technical Proposal was discussed in detail and led to its elaboration as presented in Section 5. In particular, the development of the CBA evaluation procedure has been brought forward for inclusion in the Inception Report because agreement on the approach is a prerequisite for undertaking the downstream phases of the project.

5.2 Programme

The revised work programme is presented in Table 4 and reflects the expanded duration for completing the project which now runs from 13th November, 2017 to 31st May 2018.

The sequencing of activities differs a bit from the ToR in that it is considered preferable to undertake the Desk Study as well as the detailed development of the CBA evaluation before commencing the field visits. In that way, the nature and scope of the field data collection will be informed by the outputs of these activities.

5.3 Country Visits

The timing of the data collection in Ghana, Malawi and Zambia has been tied to visits to be undertaken in the course of other on-going projects in which the project team is involved. The main data collection aspects are the unit costs of construction of the DCP-DN designed roads as discussed in Section 4.2.1. The project team is already in possession of all the DCP-DN design information for all the road sections to be evaluated.

During the country visits the selected project roads will be inspected to obtain an appreciation of their in-service performance and current condition. These visits will be coordinated with the respective National Coordinators and the ReCAP Infrastructure Research Manager.

5.4 Project Team

The Consultant's proposal to increase the size of its support team by one person was approved by the PMU. The full team is now as follows:

Core team:
Mike Pinard - Team Leader/Road Research and Technology Management Expert (TL)
Gerrie van Zyl – Cost/Benefit Expert (CBA)

Support team:
John Hine – Advisory/oversight role on CBA techniques and Value-for-Money
Phil Paige-Green - Data collection and inputs to CBA
Jon Hongve - Data collection and inputs to CBA
Estime Mukandila - Data collection and inputs to CBA (additional member)

Table 4 – Work programme

Year	2017								2018																					
Month	November				December				January					February				March				April					May			
Week starting Monday	06	13	20	27	04	11	18	25	01	08	15	22	29	05	12	19	26	05	12	19	26	02	09	16	23	30	07	14	21	28
Week number		1	2	3	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Stage 1 - Desk Study and Reporting																														
1.1 - Undertake desk study																														
1.2 - Prepare and submit Inception Report										R																				
Stage 2 - Field Visits: Meetings and Data Collection																														
2.1 - Pre-visit team meeting																														
2.2 – Ghana – Design + construction cost information																														
2.3 – Malawi - Design + construction cost information																														
2.4 – Tanzania - Design + construction cost information																														
2.5 – Kenya – Design + construction cost information																														
2.6 – Zambia - Design + construction cost information																														
2.7 – South Africa - Design + construction cost information																														
Stage 3 – Cost-Benefit Analysis and Reporting																														
3.1 – Develop CBA evaluation procedure																														
3.2 – Set up CBA evaluation matrix (spreadsheet)																														
3.3 – Populate CBA spreadsheet																														
3.4 – Undertake CBA analyses																														
3.5 – Prepare and submit draft Evaluation Report																									R					
3.6 – Present draft Evaluation Report to ReCAP PMU																														
3.6 – ReCAP PMU review of draft Evaluation Report																														
3.7 – Prepare and submit final Evaluation Report																														R

6 Summary

This Inception Report describes the initial phase of the project which principally reviewed the background to the project and carried out a desk study of alternative methods of LVR pavement design as a basis for selecting two CBR-based methods that are commonly used in the African region for comparison with the DCP-DN method by means of a life-cycle cost analysis.

The report also presents the approach and methodology to be adopted for addressing the overall aims of the project including:

- The method of cost-benefit analysis considered appropriate for use on the project.
- The principles that will be applied for determining the cost-effectiveness of the various LVR design methods under consideration.
- The manner of determining "value-for-money" offered by the various design methods.
- The manner of evaluating the outcome (uptake) of the DCP-DN design method.

Finally, the report provides an updated programme for completing the project in line with the overall project period which runs from 13th November 2017 to 31st May 2018.

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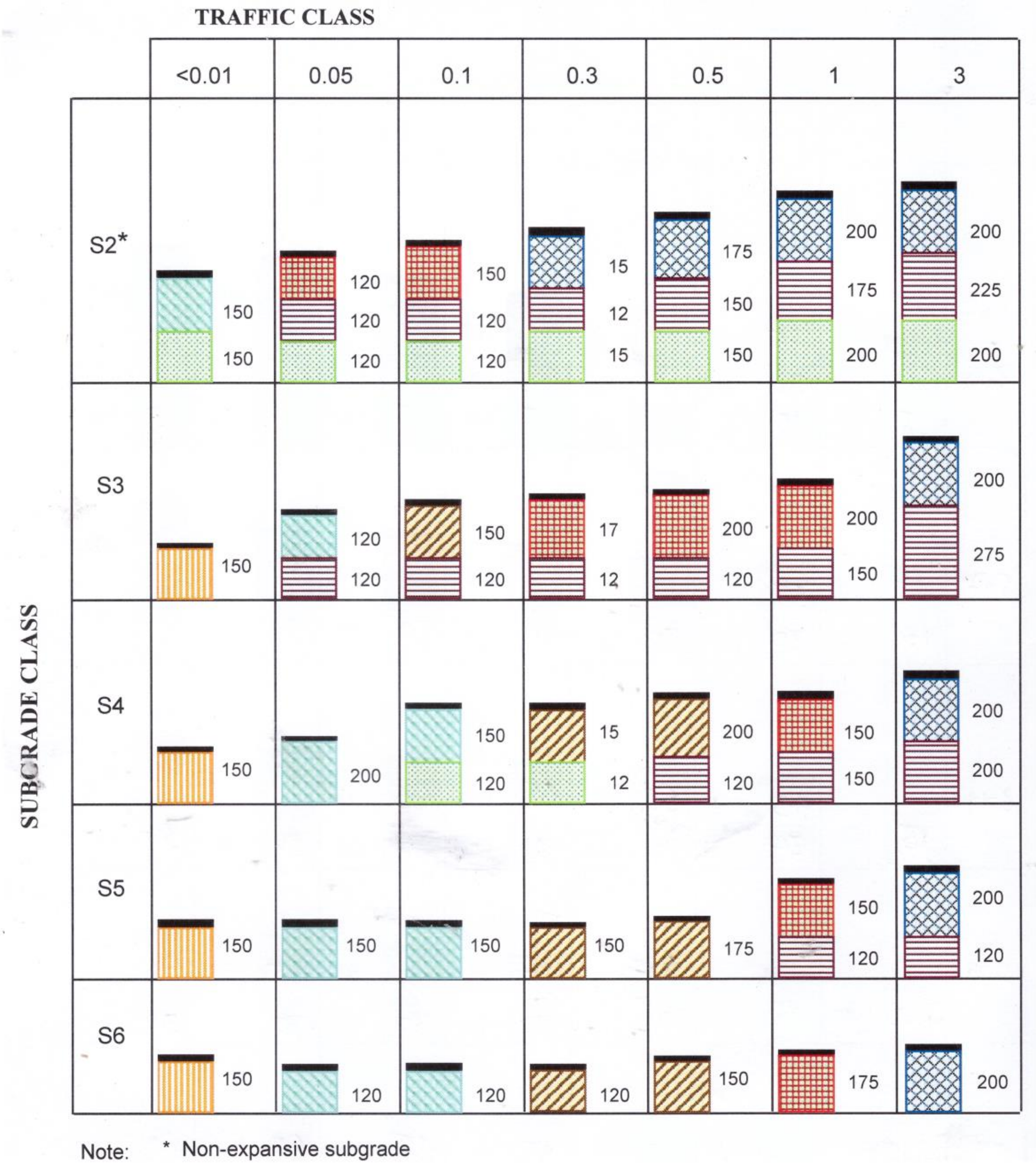
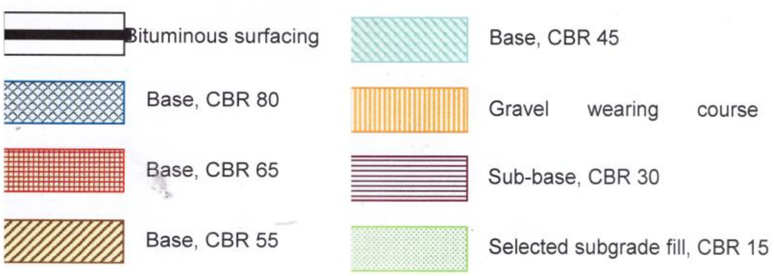
Annex A – DCP-DN Structural Design Catalogue

Traffic Class **E80 x 10^6**	**0.01** **0.003 – 0.01**	**0.03** **0.01 – 0.03**	**0.1** **0.03 – 0.10**	**0.3** **0.10 – 0.30**	**0.7** **0.30 – 0.70**	**1.0** **0.70 – 1.0**
0- 150mm Base ≥ 98% Mod. AASHTO	DN ≤ 8	DN ≤ 5.9	DN ≤ 4	DN ≤ 3.2	DN ≤ 2.6	DN ≤ 2.5
150-300 mm Subbase ≥ 95% Mod. AASHTO	DN ≤ 19	DN ≤ 14	DN ≤ 9	DN ≤ 6	DN ≤ 4.6	DN ≤ 4.0
300-450 mm subgrade ≥ 95% Mod. AASHTO	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 12	DN ≤ 8	DN ≤ 6
450-600 mm In situ material	DN ≤ 40	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 14	DN ≤ 13
600-800 mm In situ material	DN ≤ 50	DN ≤ 40	DN ≤ 39	DN ≤ 25	DN ≤ 24	DN ≤ 23
DSN 800	≥ 39	≥ 52	≥ 73	≥ 100	≥ 128	≥ 143

Annex B – DCP-CBR (TRL) Structural Design Catalogue (N > 4)



Key



Subgrade strength classes (CBR%)

S2 = 3-4
S3 = 5 – 7
S4 = 8 – 14
S5 = 15 – 29
S6 = 30^{+}

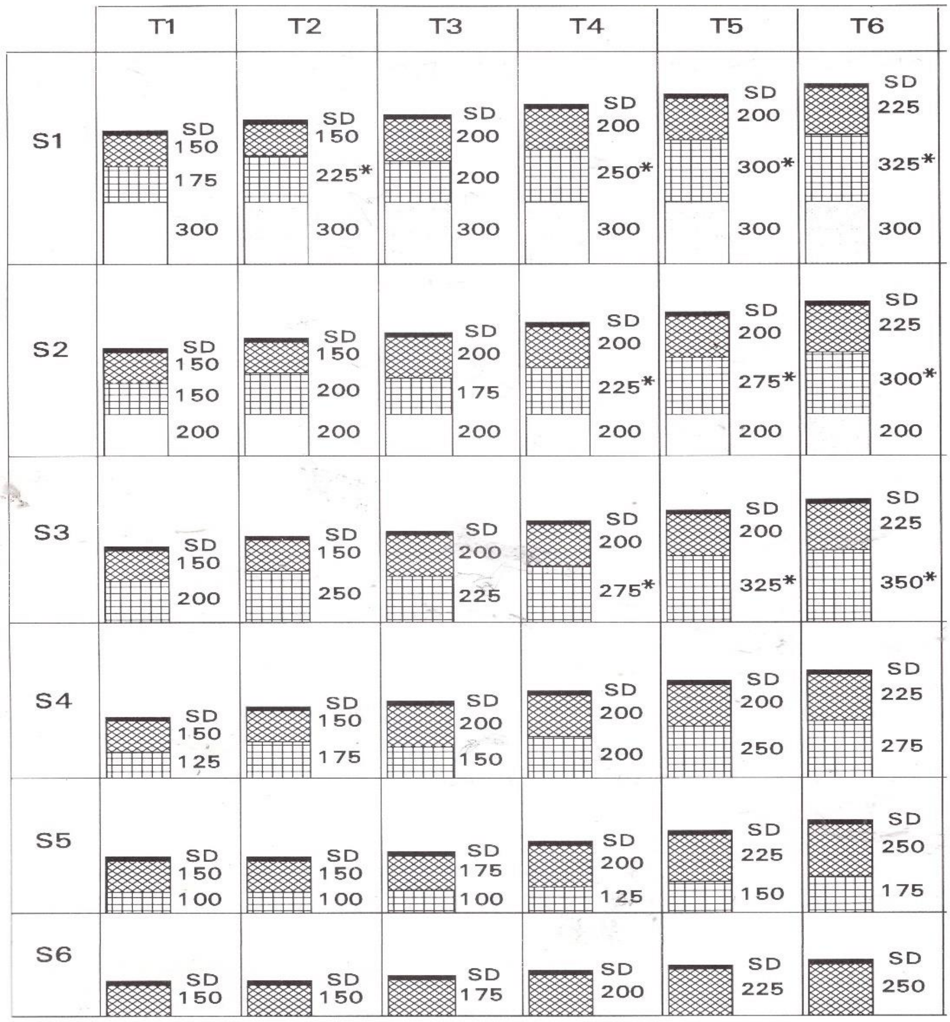
Annex C – TRH4 Structural Design Catalogue (Dry-Moderate Region)

ES0.003 < 3000	ES0.01 $0,3\text{-}1,0\times10^{4}$	ES0.03 $1,0\text{-}3,0\times10^{4}$	ES0.1 $3,0\text{-}10\times10^{4}$	ES0.3 $0,1\text{-}0,3\times10^{6}$	ES1 $0,3\text{-}1,0\times10^{6}$
					S 125 G4 150 C4 S 150 G4 150 G5
			S 100 G5 125 C4 S 125 G4 125 G6	S 125 G5 125 C4 S 125 G4 150 G6	S 125 G4 125 C4 S 125 G4 150 G5
S1 100 G5 100 G7	S1 100 G5 125 G7	S1 100 G4 125 G7	S1 100 G4 125 G6 S1 100 G5 100 C4	S 125 G4 125 G6 S 100 G5 125 C4	S 125 G4 150 G6 S 125 G5 150 C4

SYMBOL	CODE	MATERIAL	ABBREVIATED SPECIFICATIONS
	G4	Crushed or natural gravel	Minimum CBR = 80 % @ 98 % Mod. AASHTO; Maximum size 37,5 mm; 98 - 100 % Mod. AASHTO; PI < 6; Maximum Swell 0,2 % @ 100 % Mod. AASHTO. For calcrete PI ≤ 8
	G5	Natural gravel	Minimum CBR = 45 % @ 95 % Mod. AASHTO; Maximum size 63 mm or 2/3 of layer thickness; Density as per prescribed layer usage; PI < 10; Maximum swell 0,5 % @ 100 % Mod. AASHTO *
	G6	Natural gravel	Minimum CBR = 25 % @ 95 % Mod. AASHTO; Maximum size 63 mm or 2/3 of layer thickness; Density as per prescribed layer usage; PI < 12; Maximum swell 1,0 % @ 100 % Mod. AASHTO *
	G7	Gravel / Soil	Minimum CBR = 15 % @ 93 % Mod. AASHTO; Maximum size 2/3 of layer thickness; Density as per prescribed layer usage; PI < 12 or 3GM** + 10; Maximum swell 1,5 % @ 100 % Mod. AASHTO ***
	G8	Gravel / Soil	Minimum CBR = 10 % @ 93 % Mod. AASHTO; Maximum size 2/3 of layer thickness; Density as per prescribed layer usage; PI < 12 or 3GM** + 10; Maximum swell 1,5 % @ 100 % Mod. AASHTO ***
	G9	Gravel / Soil	Minimum CBR = 7 % @ 93 % Mod. AASHTO; Maximum size 2/3 of layer thickness; Density as per prescribed layer usage; PI < 12 or 3GM** + 10; Maximum swell 1,5 % @ 100 % Mod. AASHTO ***
	G10	Gravel / Soil	Minimum CBR = 3 % @ 93 % Mod. AASHTO; Maximum size 2/3 of layer thickness; Density as per prescribed layer usage; or 90% Mod. AASHTO

Annex D – ORN31 Structural Design Catalogue

Chart 1 – Granular Roadbase/Surface Dressing



Notes: 1 * Up to 100mm of subbase may be substituted with selected fill provided the subbase is not reduced to less that the roadbase thickness or 200mm whichever is the greater

2 A cement or lime-stabilised subbase may also be used